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Groundwater Quality Monitoring of Western Oil Shale Development Monitoring Program Development

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16. ABSTRACT

This report presents the development of a preliminary design of a groundwater quality monitoring program for oil shale operations, such as proposed for Federal Prototype Lease Tracts U-a and U-b in eastern Utah. The methodology used begins with a priority ranking of potential pollutant sources and includes assessments of existing or proposed monitoring programs, identification of alternative monitoring approaches, and the selection of recommended monitoring approaches.

A preliminary decision framework for monitoring design for this type of oil shale operation is presented. Included under the broad topic of the monitoring plan are recommendations for developing background data bases on pollutant source characteristics, the hydrogeologic framework of the study area, existing water quality, and infiltration, as well as recommendations for monitoring pollutant mobility. Hence needs for baseline characterization are identified and evaluated in addition to direct operational monitoring needs. A field and laboratory testing program based on these preliminary design recommendations will lead to development of a final monitoring design strategy.

A preliminary priority ranking of recommended monitoring activities is developed, based on the pollutant source priority ranking and perceived monitoring deficiencies. These priorities, along with costing data, provide a basis for cost-effectiveness assessment and thus for monitoring program selection.

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Water pollution	Monitoring methodology	08H
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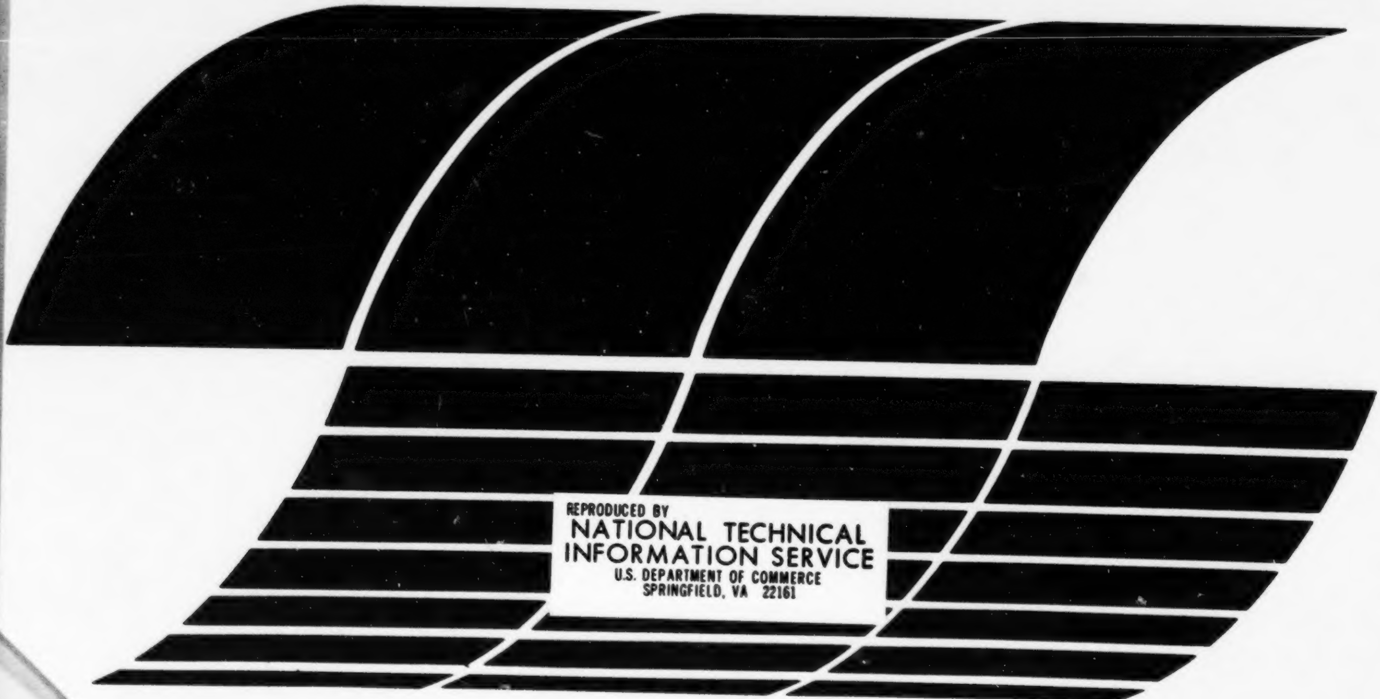

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May 1980

GROUNDWATER QUALITY MONITORING OF WESTERN OIL SHALE DEVELOPMENT:

Monitoring Program Development

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FOREWORD

Protection of the environment requires effective regulatory actions based on sound technical and scientific data. The data must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of exposure to specific pollutants in the environment requires a total systems approach that transcends the media of air, water, and land. The Environmental Monitoring Systems Laboratory at Las Vegas contributes to the formation and enhancement of a sound monitoring-data base for exposure assessment through programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment
- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs

This report concludes the initial phase of a study to design and implement groundwater quality monitoring programs for Western United States oil shale operations. An earlier report described development of a preliminary priority ranking of the potential pollution sources and the pollutants associated with these sources. This report provides a preliminary monitoring design assessment based on that priority ranking.

This study considers the type of oil shale operation proposed for Federal Prototype Oil Shale Lease Tracts U-a and U-b in eastern Utah. Proposed development plans, which include room-and-pilar mining and surface retorting and waste disposal, form the case-study evaluation presented in this report. A field and laboratory testing and verification program based on this preliminary design assessment will lead to development of final monitoring design recommendations. These recommendations are to be generic in nature and constitute a decision-design framework for groundwater quality monitoring of the general type of oil shale operations proposed for Tracts U-a and U-b. Such a framework will provide for cost-effective monitoring based on location-specific characteristics.

This planning format may be used by industrial developers and their consultants, as well as by the various local, State, and Federal Agencies with responsibilities in environmental monitoring and planning.

Further information on this study and the subject of groundwater quality monitoring in general can be obtained by contacting the Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency, Las Vegas, Nevada.

Glenn Schweitzer

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Director
Environmental Monitoring Systems Laboratory
Las Vegas

PREFACE

General Electric-TEMPO, Center for Advanced Studies, is conducting a 5-year program dealing with the design and implementation of groundwater quality monitoring programs for western oil shale development. The type of oil shale operation evaluated in this report is that presently proposed for Federal Prototype Lease Tracts U-a and U-b in eastern Utah. This type of operation includes room-and-pillar mining, surface retorting (utilizing Paraho and TOSCO II processes), and surface disposal of processed oil shale.

This study is following a stepwise monitoring methodology developed by TEMPO. The initial report in this study described the development of a preliminary priority ranking of potential pollution sources and their associated pollutants. This priority ranking has been used to develop the preliminary monitoring design assessment presented in this report.

This report provides a preliminary design format for monitoring design. The assessments include consideration of monitoring needs, monitoring alternatives, and a format for program design based on cost-effectiveness judgments. This study focuses on proposed developments on Tracts U-a and U-b as a case study for development of the monitoring design framework. A field and laboratory testing program based on this preliminary design assessment will lead to development of final monitoring design recommendations. Such future verification studies may result in reevaluation of monitoring priorities and designs.

As originally conceived, the final product of this design and verification study will be a generic planning document that provides a technical basis and a methodology for the design of groundwater quality monitoring programs for oil shale industrial developers and the various governmental agencies concerned with environmental planning and protection. Delays in construction of Tracts U-a and U-b have resulted in postponement of the verification and testing phase of this project. Thus the monitoring design strategy presented herein must be considered preliminary.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

bbl	barrel (42 U.S. gallons)
BOD	biochemical oxygen demand
CEC	cation exchange capacity
COD	chemical oxygen demand
DDP	detailed development plan
DMA	designated monitoring agency
DO	dissolved oxygen
DOC	dissolved organic carbon
EC	electrical conductivity
Eh	oxidation reduction potential
EPA	Environmental Protection Agency
ESP	exchangeable sodium percentage
FC	fecal coliform
gpm	gallons per minute
mg/l	milligrams per liter
MLSS	mixed liquor suspended solids
PAH	polycyclic aromatic hydrocarbons
ppm	parts per million
SAR	sodium adsorption ratio
SVI	sludge volume index
TC	total coliform
TDS	total dissolved solids
TOC	total organic carbon
TPC	total plate count
TPD	tons per day
WRSP	White River Shale Project

SYMBOLS

As	arsenic
B	boron
BAP	benzo(a)pyrene
Ca	calcium
$CaSO_4$	calcium sulfate
Cd	cadmium
Cl	chloride
Co	cobalt
Cu	copper
F	fluoride
Fe	iron
HCO_3	bicarbonate ion
Hg	mercury
Mg	magnesium
Mo	molybdenum
Na	sodium
$NaHCO_3$	sodium bicarbonate (nahcolite)
Ni	nickel
NO_3	nitrate ion
Pb	lead
PO_4	phosphate ion
S	sulphur
Se	selenium
SO_4	sulfate ion
Sr	strontium
Zn	zinc

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SECTION 1

SUMMARY OF MONITORING PROGRAM DEVELOPMENT

INTRODUCTION

This report is the second in a series dealing with monitoring the groundwater quality impact of western oil shale development. This particular study has addressed the impacts of oil shale operations that include deep mining, surface retorting, and surface disposal of processed or spent oil shale. The case study addressed is the proposed development of Federal Oil Shale Lease Tracts U-a and U-b in eastern Utah (Figure 1-1). The study program follows the systematic approach for groundwater quality monitoring listed in Table 1-1.

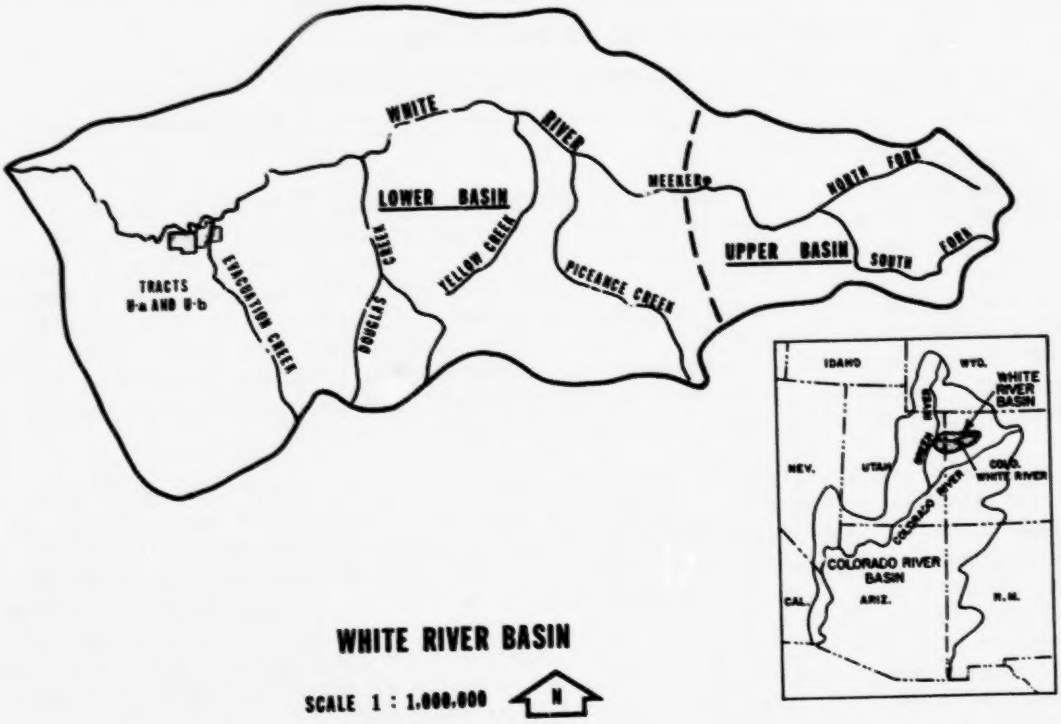
WHITE
RIVER
LOWER BASIN
MEEKER
NORTH FORK
UPPER BASIN
SOUTH FORK
TRACTS
U-a AND U-b
EVACUATION CREEK
DOUGLAS CREEK
YELLOW CREEK
PICEANCE CREEK
IDAHO
WYO.
WHITE RIVER BASIN
GREEN RIVER
NEV.
UTAH
COLO.
WHITE RIVER
COLORADO RIVER
COLORADO RIVER BASIN
CAL.
ARIZ.
N.M.
WHITE RIVER BASIN
SCALE 1 : 1,000,000
N

Figure 1-1. Map locating study area in eastern Utah (White River Shale Project (WRSP), 1976).

TABLE 1-1. STEPWISE PROCESS OF TEMPO GROUNDWATER QUALITY MONITORING METHODOLOGY

Step	Description
1	Select area for monitoring
2	Identify pollution sources, causes, and methods of disposal
3	Identify potential pollutants
4	Define groundwater usage
5	Define hydrogeologic situation
6	Describe existing groundwater quality
7	Evaluate infiltration potential of wastes at the land surface
8	Evaluate mobility of pollutants from the land surface to water table
9	Evaluate attenuation of pollutants in the saturated zone
10	Develop a priority ranking of sources and causes
11	Evaluate existing monitoring programs
12	Identify alternative monitoring approaches
13	Select and implement the monitoring program
14	Review and interpret monitoring results
15	Summarize and transmit monitoring information

As originally developed, this study was divided into three phases. The initial study was to develop a preliminary priority ranking of potential sources of impact on groundwater quality by evaluating the development plans and baseline studies for Tracts U-a and U-b; and other available more general information sources on oil shale development. The results of this initial effort have been published (Slawson, 1979; Slawson and Yen, 1979). The second study phase was to examine proposed monitoring programs for Tracts U-a and U-b, to identify information deficiencies, and to develop a monitoring design program. This work is summarized in this report.

The final study phase was to include testing and verification of proposed monitoring approaches, possibly including field tests, more intensive data analysis, and consultation with various experts involved in oil shale development and groundwater monitoring. The goal of this last study phase was to provide a basis for generalization of results of the first two phases (which, in detail, may not be characteristic of locations distant from Tracts U-a and U-b). However, recent legal questions on land ownership in the Utah oil shale region have resulted in a delay in development on Tracts U-a and U-b. As a result, these efforts have been postponed.

This report presents a preliminary framework for monitoring design using the proposed development plans for Tracts U-a and U-b as a case study.

WHITE RIVER SHALE PROJECT

Two mines, one under each lease tract, will provide raw oil shale to a common processing plant located near the boundary between the tracts (Figure 1-2). Three retort types (Paraho direct heat mode, Paraho indirect heat mode, and TOSCO II) are planned to be used for shale oil recovery. Mining and refining development is scheduled in four phases:

1. Phase I - Settle lease agreement; undertake mineral exploration; formulate and get approval of the Detailed Development Plan (DDP); conduct environmental baseline studies

2. Phase II - Sink mine access shaft to Mahogany Zone; mine maximum of 10,000 tons* per day; operate single Paraho retort; decide feasibility of commercial operation

3. Phase III - Develop commercial operation of 84,000 tons per day mining from U-b and refinery capacity of 50,000 barrels per day

4. Phase IV - Develop additional operation of 84,000 tons per day mining from U-a and increase refinery capacity of 100,000 per day.

These phases are projected to cover some 10 years before initial commercial mine operation commences and to span approximately 20 years in total. The estimated total oil shale resource recoverable during this program is 244.4 million barrels from Tract U-a and 265.8 million barrels from Tract U-b.

A more complete description of the White River Shale Project, including characteristics of potential sources of groundwater quality impact, site hydrogeologic framework, and evaluation of potential pollutant mobility, is presented by Slawson (1979). A set of compendium reports dealing with the various oil shale mining and processing techniques and environmental considerations is provided by Slawson and Yen (1979). Information on Tract U-a and U-b development plans and monitoring programs was compiled from the White River Shale Project (1976).

PRIORITY RANKING OF SOURCES OF IMPACT

A priority ranking of potential sources and causes of groundwater quality impact has been developed (Slawson, 1979). This ranking was developed from existing information on the hydrogeologic framework of the disposal area, the characteristics of the individual sources, and evaluations of

---

* See Appendix A for conversion to metric units. English units are generally used in this report because of their current usage and familiarity in industry and the hydrology-related sciences. Certain units, expressed in commonly used metric units (e.g., concentrations), are expressed as milligrams per liter or similar units.

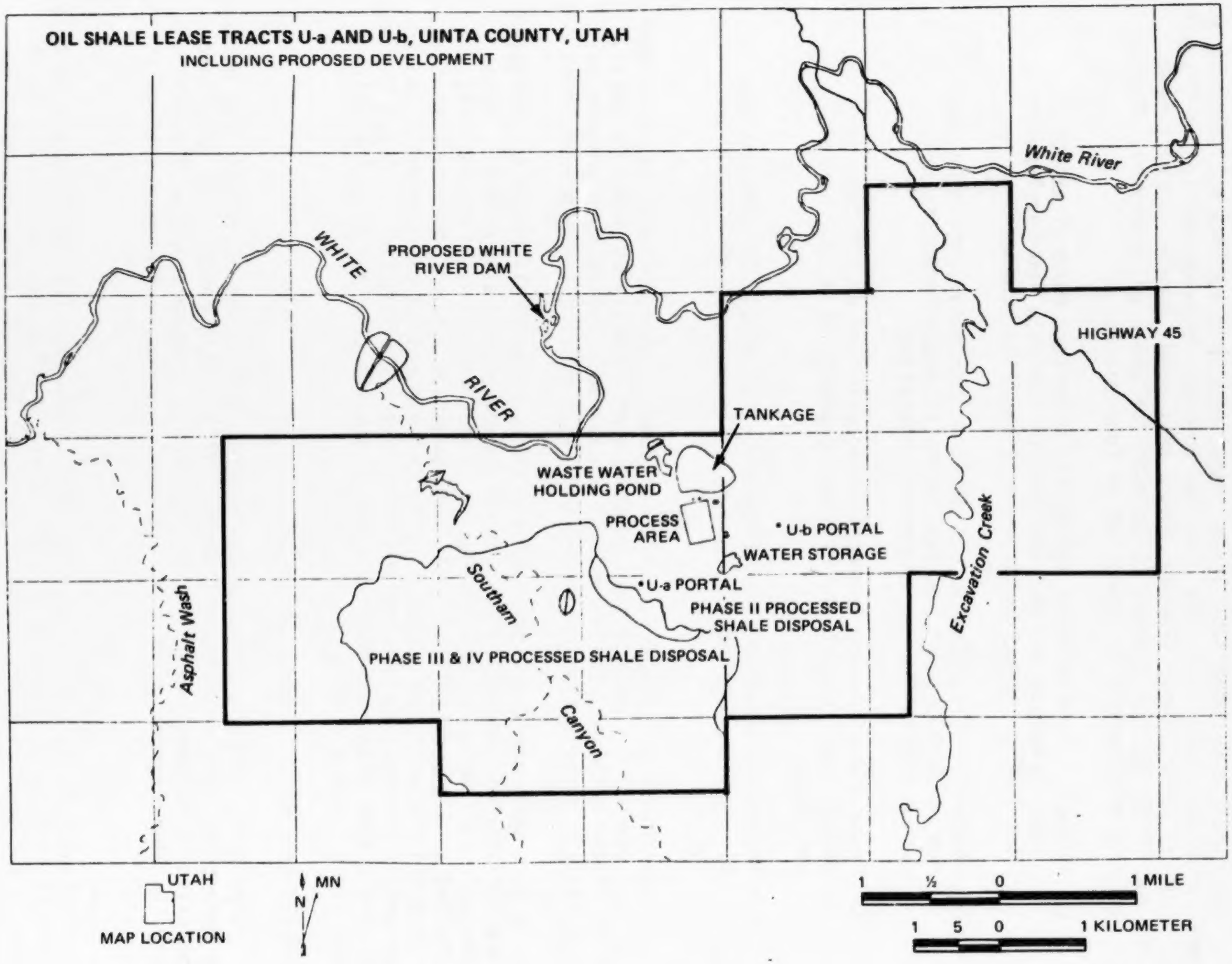
OIL SHALE LEASE TRACTS U-a AND U-b, UINTA COUNTY, UTAH
INCLUDING PROPOSED DEVELOPMENT
WHITE
RIVER
PROPOSED WHITE RIVER DAM
White River
HIGHWAY 45
TANKAGE
WASTE WATER HOLDING POND
PROCESS AREA
U-b PORTAL
WATER STORAGE
U-a PORTAL
PHASE II PROCESSED SHALE DISPOSAL
PHASE III & IV PROCESSED SHALE DISPOSAL
Southam
Canyon
Asphalt Wash
Excavation Creek
UTAH
MAP LOCATION
MN
N
1
½
0
1 MILE
1
5
0
1 KILOMETER

Figure 1-2. General development plot plan of Tracts U-a and U-b.

of potential mobility of the various waste constituents. Three criteria were used to develop the preliminary priority ranking (Table 1-2):

1. Volume of waste, persistence, toxicity, and concentration
2. Mobility
3. Potential for impact on existing potential water users.

Table 1-2 lists the three general source areas (spent-shale disposal area, process area, and retention dams) in order of overall priority for monitoring. Also, within each source area, a priority ranking of the individual potential pollutant sources is presented. These latter rankings also indicate the relative priority ranking among sources in different source areas. For example, the highest priority sources in the process area (e.g., effluent holding pond, raw shale, and tankage area) have higher priority for monitoring than the intermediate or lowest priority sources in the spent-shale disposal area.

A great deal of effort has been expended on the study of hydrogeology of the study area, and a large amount of research has been conducted on oil shale development and environmental effects. However, significant deficiencies in information exist with regard to potential pollutant characterization and the mobility of these materials in the hydrosphere. Hence, professional judgment plays an important role in proposing this preliminary pollutant-source ranking. The uncertainties associated with this priority ranking, developed from existing information, result from several sources:

- Information deficiencies on source characteristics
- Information deficiencies on disposal operations (compaction, wetting, permeability achieved, placement and scheduling, etc.)
- Information deficiencies on the hydrogeology of the source areas
- Uncertainties in evaluating mobility processes (infiltration, pollutant attenuation, etc.).

The first three of these factors relate to deficiencies in background information needed to design an adequate monitoring program. These factors are very site specific. Although clearly interrelated to the other three, the fourth factor is also associated with pollutant-source monitoring directly. Addressing such deficiencies or uncertainties is the function of monitoring design development presented in this report.

Following development of the priority ranking, the next step in the development of a monitoring program is to assess existing or proposed monitoring programs with regard to capability for addressing these information deficiencies. In the following sections, each of the major source areas (spent-shale disposal area, process area, and retention dams) will be considered and existing or proposed monitoring plans for Oil Shale Tracts U-a and U-b will be presented. Information deficiencies with regard to source

TABLE 1-2. PRELIMINARY RANKING OF POLLUTANT SOURCES AND POLLUTANTS FOR OIL SHALE TRACTS U-a AND U-b

Source area	Source priority ranking	Potential pollution source	Potential pollutant ranking		
			Highest	Intermediate	Lowest
Spent shale disposal area	Highest	Spent shale	TDS, Na, SO_4, As, Se, F, organics (PAH)	CA, Mg, Zn, Cd, Hg, B, organics (e.g., phenols)	Pb, Cu, Fe
		High TDS waste water	TDS	---	---
		Sour water	Ammonia, phenols	Organics	---
		Retort water	As, Cl, S, organics (POM, carboxylic acids, phenols)	TDS, organics (amines, etc.)	Carbonates, PO_4, NO_3
		Spent catalysts	As, Mo	Zn, Ni	Fe, Cu, Co
	Intermediate	Storm water runoff	TDS, organics, As, Se	Na, Ca, SO_4, HCO_4, organics	Zn, Cd, Hg
		Water treatment plant sludges	TDS	Major inorganics	Trace metals
		Miscellaneous landfill materials	Organics	---	---
		Sulfur byproducts	Sulfides, sulfates	---	---
		Oily waste waters	Organics	Trace metals	---
		Spent filters	Organics, As	Trace metals	---
	Lowest	Sewage sludge	Organics	Nutrients	---
		Mine water	TDS, oil and grease	Trace materials, organics	Major inorganics
		Sanitary waste water	Organics	Nutrients	Major inorganics
		Surface disturbance	Calcium salts, TDS	Major inorganics	---
Process area	Highest	Effluent holding pond	TDS, organics	Trace metals, nutrients	---
		Raw shale	TDS, As, Se, organics	Major inorganics	Trace metals
		Tankage area	Miscellaneous fuels, oil additives, ammonia, TDS	---	---
	Intermediate	Storm water runoff	TDS, organics	Major inorganics	---
		Miscellaneous process waste streams	TDS, organics, ammonia	Major inorganics, trace metals	Nutrients
	Lowest	Surface disturbance	Calcium salts, TDS	Major inorganics	---
Retention dams	(Sources same as spent shale disposal area)		TDS, organics (PAH, phenols, etc., As, Se, Mo, ammonia, Na, SO_4	Ca, Mg, Zn, Ni, Cd, Hg, organics	Pb, Cu, Fe, nutrients

characterization, development plans, the hydrogeologic framework of the source areas, and monitoring of pollutant mobility will be identified for each of the source areas. Design of a recommended monitoring program will include consideration of alternative measures for addressing these deficiencies. The design and implementation of the recommended program calls for selection of the most cost-effective alternatives. A framework for this decision process is presented in this report.

MONITORING DESIGN APPROACH

The implementation of the ranking scheme calls for three iterations through the steps of the monitoring methodology. Each consideration of the methodology sequence is at a different level of detail and is intended to accomplish different goals. With each iteration, the overall monitoring design program progresses further toward attaining the ultimate monitoring goals embodied in Public Law 92-500, Public Law 93-523, and other legislation.

Level One Ranking

The priority ranking presented in Table 1-2 represents a first pass through the monitoring methodology and is termed the level one ranking.

The first time through the ranking scheme, several objectives are met:

- Review of the existing data and information on known and potential sources and causes of impact on groundwater quality
- Identification of potential pollutants associated with these sources and causes
- Evaluation of the hydrogeologic framework in the project insofar as it relates to these sources and causes
- Superimposition of these potential sources and causes of impact on the hydrogeologic framework to evaluate mobilities of potential pollutants.

Level Two Ranking

Implementation of the monitoring program will require a return to the beginning of the ranking steps. This time the objective will be to verify the preliminary ranking sources with hard data. Considerable time may be involved in this exercise, depending on the number of sources involved and the size of the area; several years to a decade or more may be needed for this program to mature. These monitoring efforts may result in a revision of the original priorities. Some monitoring activities may have to be decreased or eliminated, while others may need to be intensified.

Utilizing the results of the second pass through the ranking scheme, a much more accurate estimate of the threat to the area's groundwater quality will be available, and controls can be devised to deal with the threat. If the need for instituting controls is obvious after the first preliminary ranking, controls should be implemented at that time. The implementation of controls will again require funding by the appropriate State agency.

Level Three Ranking

The final iteration of the ranking steps will involve monitoring to check on the effectiveness of the controls that are implemented. If these controls prove effective, then the intensity of monitoring can be reduced and eventually dropped if the threat can be shown to no longer exist. New sources of potential pollution may continually appear. The monitoring program should include evaluation of these sources.

MONITORING PROGRAM DEVELOPMENT

The following sections present the development of the groundwater quality monitoring program for oil shale development as proposed on Tracts U-a and U-b. Monitoring of the processed-shale disposal area is presented in Section 2; the process area is considered in Section 3; and the retention dams are considered in Section 4. For each of these source areas, proposed or existing monitoring plans are presented and an assessment of monitoring deficiencies is developed (methodology step 11). Then alternative approaches for addressing these deficiencies are presented (methodology step 12). Finally a monitoring program plan is developed based on perceived monitoring deficiencies and the priority ranking of pollutant sources and causes presented in the preceding discussion.

The evaluations resulting in monitoring program development plans for each of the three major source areas included consideration of trade-offs among the various recommended monitoring activities within each of the three areas (see Tables 2-8, 3-4, and 4-2). Obviously, similar trade-offs between activities in the different source areas may also be made for finalizing monitoring plans for the project as a whole. The bases for making such trade-offs, both within and among the source areas, are the preliminary priority ranking of potential pollutant sources and causes (methodology steps 1 through 10), the perceived deficiencies in existing knowledge and proposed monitoring plans (methodology step 11), and the evaluation of alternative approaches for satisfying these monitoring deficiencies (methodology step 12). Cost considerations are also a key part of the finalizing priorities for monitoring program development activities. These technical considerations (i.e., capability for satisfying the monitoring goals of pollutant detection, evaluation, and control) and cost considerations essentially constitute a cost-benefit or cost-risk evaluation. Such an evaluation is presented in the following discussions as an illustration of the decision framework and process.

GENERAL MONITORING RECOMMENDATIONS

Although the application of the monitoring approaches presented in this report have not been verified, several general monitoring guidelines are implicit in these results. Many of the information deficiencies identified relate to characterization of the site hydrogeologic framework. Preliminary monitoring recommendations are as follows:

- Baseline studies need to focus closely on the locations of potential sources of groundwater impact including:
  - -- Infiltration
  - -- Characterization of soils and alluvial system
  - -- Identification and characterization of deep aquifers
  - -- Interrelationship between different aquifer zones and between surface waters and groundwater bodies
- Pile construction, irrigation, revegetation, etc. will significantly influence infiltration potential and monitoring needs for surface disposal operations
- The unsaturated zone in surface disposal piles and underlying soils, alluvium, or consolidated formations should be a major focus of monitoring programs
- Modifications in the hydrogeologic framework from mine-induced subsidence or reservoir filling may appreciably alter subsurface flow dynamics and hence should be monitored closely.

In addition, monitoring programs should be flexible and responsive to the changes observed. Such responsiveness may result in alteration of monitoring needs and priorities. For example:

- Sampling frequencies should be adjusted in response to the interpretation of monitoring data: less frequent sampling is indicated where a low probability of change or impact is concluded; more frequent sampling is warranted should changes (e.g., in moisture content, water level, or water quality) be observed.
- Initial monitoring may best be focused on monitoring of the sources themselves (e.g., within the spent-shale pile) and shallow hydrogeologic strata (e.g., alluvium or Uinta Formation in this case study) with lesser emphasis on deeper aquifer units (e.g., Bird's Nest or Douglas Creek Aquifers).
- Observed water quality impacts at sources or in shallow hydrogeologic strata or changes in the hydrogeologic framework may require more intensive monitoring of these deep aquifers.

Thus monitoring programs should be continually subject to review and adjustment of priorities.

PRIORITY TRADE-OFFS

Priority trade-offs among the various monitoring activities within each of the three source areas are presented in Tables 2-8, 3-4, and 4-2. Drawing from these, priority trade-offs between the source areas may also be developed. The basic process here is to take the ranked items within each area and to develop a ranking (from highest to lowest priority) for this total set of activities for each of the methodology steps. For example, consider the following illustration. Within each source area:

- From Table 2-8, the highest priority items for the processed-shale disposal area for pollutant-source characterizations are:
  - -- Surveys of development activities
  - -- Waste chemical analyses
- From Table 3-4, the highest priority items for the process area for pollutant-source characterization are:
  - -- Surveys of development activities
  - -- Waste chemical analyses (waste-water holding pond and raw shale
- From Table 4-2, the highest priority items for the retention-dams area for pollutant-source characterization are:
  - -- Surveys of development activities
  - -- Chemical analysis of retention basin water.

These monitoring activities as a set can then be ranked from highest to lowest, constituting a ranking between source areas. The general basis for this ranking is the same as that used to rank activities within each source area.

Continuing this process for each set of monitoring activities results in an overall priority trade-off matrix, such as illustrated in Table 1-3. This matrix provides a listing of relative priority of each monitoring activity, the descending order of priority being from top to bottom of Table 1-3.

COST INFORMATION

Evaluation of cost is a key aspect of monitoring program development. Preliminary cost estimates for the various monitoring activities ranked in Table 1-3 are presented in Table 1-4. Details of the derivation of these cost data are provided in Appendix B of this report. These cost estimates are provided here for two reasons.

1. To provide an approximate measure of the costs of the various recommended monitoring activities
2. To provide an illustration of a format for cost-benefit assessments.

TABLE 1-3. PRIORITY TRADE-OFFS WITHIN AND BETWEEN THE THREE SOURCE AREAS

Priority ranking—trade-offs within a source area	Priority ranking—trade-offs between source areas	Overall relative priority ranking	Monitoring methodology steps				
			Pollutant-source characterization	Water use	Hydrogeology and water quality	Infiltration	Pollutant mobility
Highest	Highest	1	Surveys of development activities: a. Processed-shale disposal area b. Process area c. Retention-dam areas		Geophysical surveys and test drilling of alluvium: a. Processed-shale disposal area b. Process area c. Retention-dam areas	Infiltrometer tests a. Processed-shale pile b. Retention basins in Southam Canyon and in process area Sensor evaluations in processed shale	Monitoring in processed shale pile
	Intermediate	2	Waste chemical characterization: [general, major inorganic, trace metals, organics] a. Processed shale b. High TDS waste water c. Sour water d. Spent catalysts e. Process area waste water holding pond f. Retention basins		Installation and testing of new wells Sampling of new wells	Infiltrometer tests: a. Alluvium of Southam Canyon b. Tankage area c. Stockpile areas (process area)	Monitoring within the retention dams
	Lowest	3	Chemical characterization as above: a. Water treatment plant sludge b. Sulfur byproducts c. Oily waste waters d. Spent filters e. Raw shale f. Tankage products g. Mine water		Surveys of fracturing in the Uinta and Green River Formations Evaluate water quality sampling procedures for deep aquifers Identification and characterization of saturated zones above Bird's Nest Aquifer	Infiltration tests in Uinta formation a. Processed-shale disposal area b. Process area c. Retention dam basins	Monitoring in alluvium of the process area
Intermediate	Highest	4	Waste chemical characterization as above: a. Product streams in process area b. Runoff (washoff) in process area		Sampling of existing alluvial wells in the processed-shale disposal area		Monitoring in the alluvium of the processed shale disposal area

(continued)

TABLE 1-3 (CONTINUED)

Priority ranking—trade-offs within a source area	Priority ranking—trade-offs between source areas	Overall relative priority ranking	Monitoring methodology steps				
			Pollutant-source characterization	Water use	Hydrogeology and water quality	Infiltration	Pollutant mobility
Inter-mediate	Inter-mediate	5				Infiltrometer tests: a. Near plant facilities b. Near waste water treatment plant	Monitoring in the Uinta Formation and Green River Formation above Bird's Nest Aquifer in the process area
	Lowest	6		Regional water use survey		Infiltrometer tests: a. Water supply holding basin b. Near soils stockpile	Monitoring of the Uinta Formation and Green River Formation above Bird's Nest Aquifer in the processed-shale disposal area
Lowest	Highest	7	Waste chemical characterization as above: a. Waste water treatment plant b. Water storage basin				Monitoring in the Uinta Formation and Green River Formation in the retention-dam area
	Inter-mediate	8	DOC fractionation analysis of above potential pollution sources		Test existing wells (if possible)in Bird's Nest Aquifer: a. Processed-shale disposal area b. Process area Install and test new wells in Bird's Nest Aquifer in processed-shale disposal area		Monitoring in the Bird's Nest Aquifer of processed-shale disposal area
	Lowest	9	Radiological and bacteriological analyses of above potential pollutant sources		Test existing wells (if possible) in Bird's Nest Aquifer in retention dam areas. Install and test new wells in Bird's Nest Aquifer: a. Process area b. Retention-dam area Install and test new wells in Douglas Creek Member: a. Processed-shale disposal area b. Process area c. Retention-dam areas		Monitoring in Bird's Nest Aquifer: a. Process area b. Retention-dam areas Monitoring in the Douglas Creek Member

TABLE 1-4. SUMMARY OF PRELIMINARY COST ESTIMATES FOR RECOMMENDED MONITORING ACTIVITIES[a]

Priority ranking -- trade-offs within a source area	Priority ranking-- trade-offs between source areas	Overall relative priority ranking	Estimated annual costs in 1978 dollars for each phase and year of development (thousands of dollars)					
			First year Phase II	Thereafter Phase II	First year Phase III	Thereafter Phase III	First year Phase IV	Thereafter Phase IV
Highest	Highest	1	61	22	42	29	35	23
	Intermediate	2	83	11	68	12	8	8
	Lowest	3	150	32	62	32	28	28
Intermediate	Highest	4	16	8	11	14	5	5
	Intermediate	5	8	2	7	2	2	2
	Lowest	6	5	2	5	1	5	1
Lowest	Highest	7	7	1	7	1	1	1
	Intermediate	8	198	7	124	9	8	8
	Lowest	9	435	6	115	9	7	7

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[a] Detailed information used to develop these estimates is provided in Appendix B of this report.

[b] See Table 1-3 for description of monitoring activities for each relative ranking level.

General management and data management costs have not been included in these estimates because these cost items will vary greatly depending on the level of effort and funding finally determined for the monitoring program. In addition, inflation effects have been ignored for this exercise. Table 1-4 then provides a "first-cut" costing for the monitoring activities ranked in Table 1-3.

The selection of a monitoring program may proceed as follows: Given a proposed level of funding (or more likely a funding schedule over some defined planning horizon), tables such as Tables 1-3 and 1-4 provide a basis for identification of the monitoring activities allowed by that funding schedule. This is essentially equivalent to a cost-benefit statement (i.e., for this defined expenditure, the types of monitoring data obtained are identified).

The monitoring activities not provided by a proposed level of funding can be identified in the same manner and increments of additional funding needed to include various additional activities can be estimated. This is essentially a basis for a cost-risk assessment (i.e., by not spending some indicated amount, we risk not having certain defined types of monitoring data).

For example, given a budget of $100,000 per year, a 5-year plan of action (ignoring inflation) for Phase II monitoring can be developed from the initial-year and operation-year costs for each monitoring item ranked in Table 1-4. A preliminary program and costing is provided in Table 1-5.

Because of the manner in which the priority rankings were developed, the most important pollution sources are addressed (funded) first. In this fashion, the quality of cost-effectiveness is embodied in the final design; for a given economic constraint, the most important monitoring data are collected.

Another important consideration is that monitoring needs or priorities can be expected to vary over time. Initial monitoring activities (based on assessments such as presented in Slawson (1979) and the following sections of this report) will provide new insight into definition of the potential for pollution from the various sources identified, identification of chemical constituents likely to be mobile and thus needing to be monitored most closely, and determination of appropriate sampling sites and frequencies. Changing regulatory requirements may also lead to modification of monitoring requirements. For example, regulations and State implementation programs addressing the hazardous-waste-handling aspects of the Resources Conservation and Recovery Act of 1976 may have an appreciable impact on waste-disposal programs and monitoring needs for oil shale development. In addition, development of new monitoring technologies (e.g., new analytical methods or field instrumentation) and the results of research on oil shale may lead to modification of monitoring requirements. Hence, monitoring design must be viewed as a continuing process rather than a singular task of evaluation, design, and implementation. Continuing reassessment is required in order to achieve continuing cost-effectiveness.

Table 1-5. EXAMPLE 5-YEAR PROGRAM DEVELOPMENT AND COSTING TAKEN FROM PRIORITIES AND COST DATA GIVEN IN TABLE 1-4.

Monitoring program year	Monitoring program description: Item[a]	Monitoring program description: Discussion	Estimated cost (thousands of 1978 dollars)
1	1	Initiate totally	61
	2	Initiate partially	39
		Year 1 subtotal	100
2	1	Operate	22
	2	Operate segment initiated year 1	5
	2	Initiate segment deferred year 1	44
	3	Initiate partially	29
		Year 2 subtotal	100
3	1	Operate	22
	2	Operate	11
	3	Operate segment initiated year 2	6
	3	Initiate an additional segment	61
		Year 3 subtotal	100
4	1	Operate	22
	2	Operate	11
	3	Operate segments initiated years 2 and 3	19
		Initiate an additional segment	48
		Year 4 subtotal	100
5	1	Operate	22
	2	Operate	11
	3	Operate segments initiated years 2, 3, and 4	29
	3	Initiate deferred segment	12
	4	Initiate totally	16
	5	Initiate totally	8
	6	Initiate partially	2
		Year 5 subtotal	100

[a] Items: Sets of monitoring activities defined by relative ranking numbers, Tables 1-3 and 1-4 (column 3 in each table).

SECTION 2

MONITORING DESIGN DEVELOPMENT FOR THE PROCESSED-SHALE DISPOSAL AREA

INTRODUCTION

The spent-shale disposal area, as described by the White River Shale Project (1976), will be a conglomeration of several potential pollution sources. Waste products include spent shale (Paraho and TOSCO II), high total dissolved solids (TDS) waste waters, retort waters, spent catalysts, treatment plant sludges, and numerous other solid and liquid wastes. A preliminary ranking of these waste components in the spent-shale disposal area has been developed (Table 2-1).

PROPOSED OR EXISTING MONITORING PROGRAMS

The Detailed Development Plan (White River Shale Project, 1976) includes a monitoring plan for oil shale operations proposed for Tracts U-a and U-b. The proposed hydrologic monitoring program is presented in Table 2-2 and Figure 2-1. The following summarizes those plans for monitoring the proposed oil shale operation:

- Quarterly water quality sampling of major inorganic, trace metal, and general organic measures in the alluvium:
    - -- Generally upgradient from the main disposal area
    - -- At two locations downstream from the Phases III and IV retention dam
    - -- Along the White River upstream from its junction with Southam Canyon
- Water quality sampling from temporary, shallow alluvial wells near the toe of the spent-shale pile; temporary wells will be removed when encroached upon by pile development
- Monitoring of Bird's Nest Aquifer, generally up- and downgradient from the disposal area, and the Douglas Creek Aquifer to the east of the disposal area; this monitoring includes water-level measurement at several sites and water quality sampling at selected wells

TABLE 2-1. PRELIMINARY RANKING OF POLLUTANT SOURCES INCORPORATED IN SPENT-SHALE DISPOSAL AREA

Source priority ranking	Potential pollution source	Potential pollutant ranking		
		Highest	Intermediate	Lowest
Highest	Spent shale	TDS, Na, SO_4, As, Se, F, organics (PAH, carcinogens)	Ca, Mg, Zn, Cd, Hg, B, organics (phenols, etc.)	Pb, Cu, Fe
	High-TDS waste water	TDS	---	---
	Sour water	Ammonia, phenols	Organics	---
	Retort water	As, Cl, S, organics (POM, carboxylic acids, phenols)	TDS, organics (amines, etc.)	Carbonates, PO_4, NO_3
	Spent catalysts	As, Mo	Zn, Ni	Fe, Cu, Co
Intermediate	Storm water runoff	TDS, organics, As, Se	Na, Ca, SO_4, HCO_3, organics	Zn, Cd, Hg
	Water treatment plant sludges	TDS	Major inorganics	Trace metals
	Miscellaneous landfill materials	Sulfides, organics	Sulfides	---
	Sulfur byproducts	Sulfides, sulfates	---	---
	Oily waste waters	Organics	Trace metals	---
	Spent filters	Organics, As	Trace metals	---
Lowest	Sewage sludge	Organics	Nutrients	---
	Mine water	TDS, oil and grease	Trace metals, organics	Major inorganics
	Sanitary waste water	Organics	Nutrients	Major inorganics
	Surface disturbance	Calcium salts, TDS	Major inorganics	---

[a] From Slawson, 1979

TABLE 2-2. SUMMARY OF GROUNDWATER MONITORING PROGRAM PROPOSED BY WHITE RIVER SHALE PROJECT (WRSP, 1976)

Well identification(s)[a]		Aquifer	Well depth (feet)	Sampling frequency	Parameters measured	Sampling methods and miscellaneous information
AG-1 Upper	U[b]	Alluvial	12	Quarterly[d]	Macroinorganics: Ca, Mg, K, Na, Cl, F, SO_4 General: pH, specific conductance, temperature, total alkalinity, TDS Trace: As, B, Hg, Mo, Se, Si, sulfide Organic: TOC, total carbon	Sampling and treatment: as per USGS methods[f] Analysis: as per APHA methods[g] Sampling: Pump for large wells, bailer or thief sampler for small wells
Lower	U	↓	44	↓		
AG-2 Upper	D[c]		21			
Lower	D		40			
AG-3 Upper	D		20			
Lower	D		38			
AG-6	D		27			
AG-7			37			
AG-8	U		20			
AG-9	U		20			
G-2A	D	Alluvial	41	Quarterly		
P-2 Upper	D	Bird's Nest	378	Semiannual[e]		
Lower	D	↓	519			
P-3	U		540			
G-11	U		650		Depth to water	Steel tape or electric probe
G-21	D	Bird's Nest	611	Semiannual		
P-1		Bird's Nest	488	Quarterly		
P-4		Douglas Creek	400	↓		
X-5		Bird's Nest	936			
G-5		↓	620			Steel tape, electric probe, or continuous recorder
G-8A			100		Depth to water	
G-8			127			
G-10			400			
G-12			100			
G-14		Bird's Nest	90	Quarterly		
Shallow well(s) in vicinity of spent shale pile		Alluvial	Shallow	Quarterly	Water chemistry as listed above	Wells abandoned as encroached upon by shale disposal

[a] Sampling locations are shown in Figure 2-1.

[b] U: upgradient from processed shale deposit

[c] D: downgradient from processed shale deposit

[d] Quarterly sampling periods: February-March, May-June, August-September, and November-December

[e] Semiannual sampling periods: May-June and November-December

[f] U.S. Geological Survey (1970)

[g] American Public Health Association (1976)

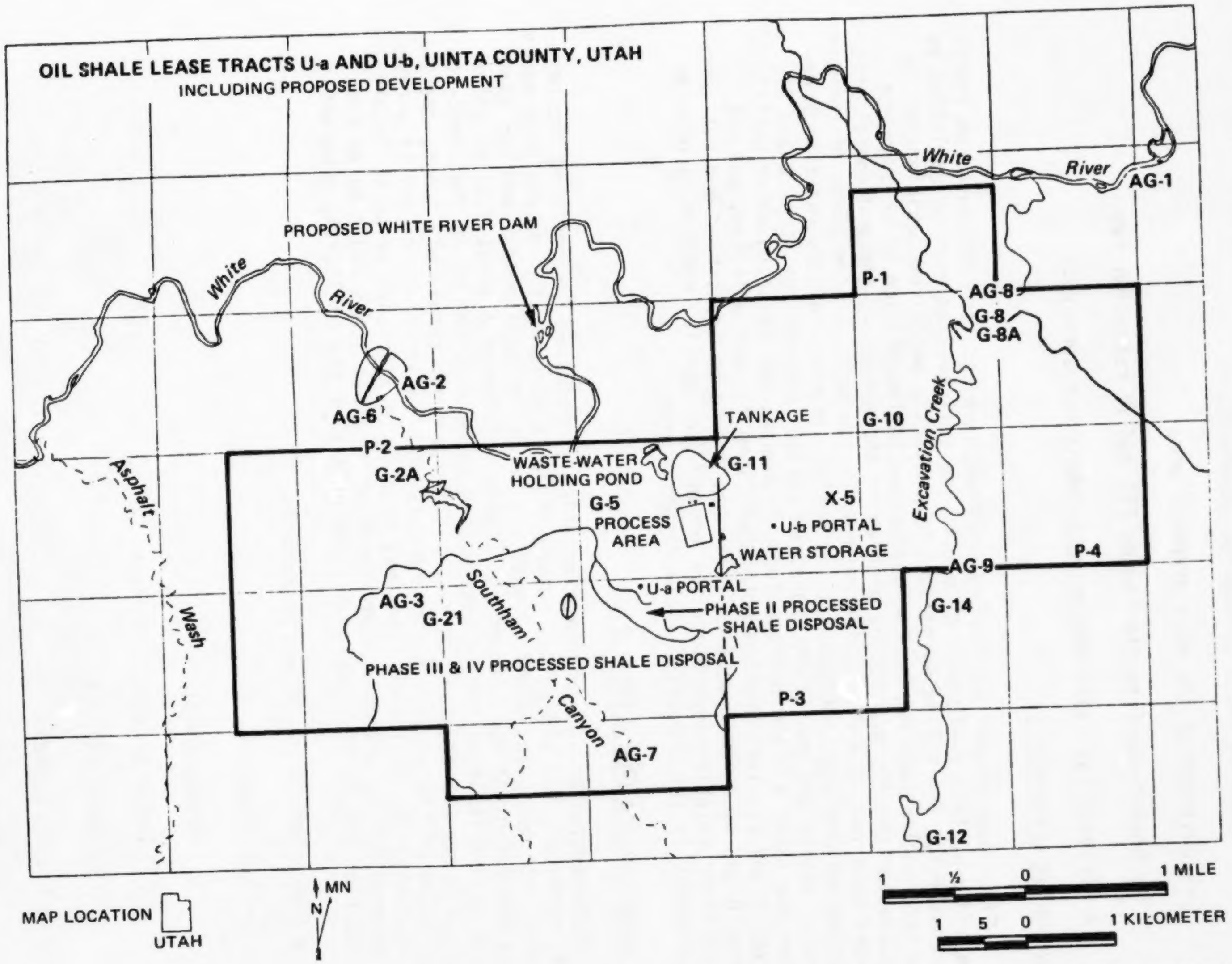

OIL SHALE LEASE TRACTS U-a AND U-b, UINTA COUNTY, UTAH
INCLUDING PROPOSED DEVELOPMENT
PROPOSED WHITE RIVER DAM
White
River
White
River
AG-1
P-1
AG-8
G-8
G-8A
AG-2
AG-6
Asphalt
Wash
TANKAGE
G-10
Excavation Creek
P-2
WASTE-WATER
HOLDING POND
G-11
G-2A
G-5
PROCESS
AREA
X-5
• U-b PORTAL
WATER STORAGE
AG-9
P-4
• U-a PORTAL
PHASE II PROCESSED
SHALE DISPOSAL
AG-3
G-21
Southham
G-14
PHASE III & IV PROCESSED SHALE DISPOSAL
P-3
Canyon
AG-7
G-12
1 ½ 0 1 MILE
1 5 0 1 KILOMETER
MN
N
MAP LOCATION
UTAH

Figure 2-1. Groundwater monitoring sites on Tracts U-a and U-b proposed by White River Shale Project (WRSP, 1976) (see Table 2-2).

- Precipitation monitoring, stream gaging, and surface-water quality sampling (when streamflow observed):
  - Upstream of the main disposal area
  - Downstream from the Phases III and IV retention dam
- Periodic (at least semiannual) subsidence surveys.

MONITORING DEFICIENCIES

Since operational monitoring programs have not been initiated on Tracts U-a and U-b, this evaluation of monitoring deficiencies must be qualified to some extent. The following paragraphs summarize perceived deficiencies in the information base needed for design and implementation of an adequate groundwater quality monitoring program in the processed-shale disposal area. Toward this end, the discussion returns to the initial nine steps of the monitoring methodology (Section 1). Potential information gaps exist with regard to source and pollutant characterization (methodology steps 2 and 3), water use (step 4), the hydrogeologic framework and existing water quality (steps 5 and 6), infiltration potential (step 7), and pollutant mobility (steps 8 and 9). These data deficiencies are to be identified and evaluated as to their relative importance for groundwater quality monitoring program development in the processed-shale disposal area.

Pollutant-Source Characterization

Information on source characteristics is required for defining the physical, chemical, and biological nature of waste streams, for determining waste loading, for assessing chemical analysis needs for monitoring, and for examining the potential mobility of pollutants. Although a great deal of information is available on the various wastes to be disposed of in the spent-shale disposal area, the chemical characteristics are not completely known, and the interaction of the various waste products with infiltrating waters is unclear. Consequently, the following items may need to be addressed prior to finalizing the monitoring program. Consideration of these items would be an integral part of the initial implementation phases of the monitoring program:

- Characterization of waste products
  - Solid wastes
    - (1) Processed shale
    - (2) Water treatment sludges
    - (3) Spent filters
  - Liquid wastes
    - (1) High-TDS waste water

(2) Sour water

(3) Retort water

(4) Water mixtures used to moisturize waste shale

(5) Oily waste waters

(6) Mine water

- Waste-water interactions
  - "Soil" moisture (or soil-water) characteristic curves for spent shale and other solid wastes
  - Leaching potential (qualitative and quantitative assessment) under saturated and unsaturated conditions.

The details of construction and operation procedures greatly influence the potential for pollutant mobility. The design of the spent-shale pile is, in many ways, conceptual at this time. Pile design features that need to be known prior to finalizing monitoring efforts include the following:

- Actual procedures (time sequence) for spreading, contouring, and compacting of spent shale
- Placement of other solid wastes, including timing, location (localized or diffuse), treatment, and covering
- Details of revegetation program
  - Timing
  - Details of trench construction and filling
  - Leaching program (if any)
  - Irrigation practice (if any)
  - Type and survival of sealants for water harvesting.

Water Use

An important aspect of the monitoring program should be provision for periodic regional water-use surveys. Although use of groundwaters in the immediate project region is limited at this time, increased use of both surface waters and groundwater can reasonably be expected with future acceleration of oil shale development.

Hydrogeologic Framework and Existing Water Quality

Site hydrogeology is a determining factor in natural water quality and is a key influence on pollutant mobility. Thus hydrogeologic data play an important role in the design of a monitoring program. The hydrogeologic framework can be described in terms of the alluvium, the Uinta Formation, the Bird's Nest Aquifer, and the Douglas Creek Member. In constructing the processed-shale pile, the vadose zone locally is substantially thickened. Hence evaluation of the hydraulic properties of the disposal pile, as well as underlying strata, is also needed. Such evaluations are presented in later discussions of infiltration and pollutant mobility. Data deficiencies in the spent-shale disposal area include the following:

- Characterization of alluvium
  - -- Thickness and subsurface extent of alluvium
  - -- Moisture status (e.g., existence of saturated layers)
  - -- Spatial heterogeneity in physical properties (e.g., particle-size distribution, clay content) and chemical properties (e.g., cation exchange capacity, pH, etc.)
  - -- Aquifer characteristics (e.g., transmissivity and storage coefficient)
  - -- Depth to water and direction of groundwater movement
- Soil mositure characteristic curves for alluvium, soils, and Uinta sandstones
- Fracturing in the Uinta Formation
- Presence and characteristics of saturated zones in the Uinta Formation (e.g., near the White River)
- Aquifer characteristics of Bird's Nest Aquifer; three wells were pump tested and only one of these is near the potential pollution source areas
- Aquifer characteristics of the Douglas Creek Aquifer.

Alluvium--

Several observation wells have been installed in the alluvium of the White River, Evacuation Creek, Southam Canyon, and Asphalt Wash. On a regional basis, there are several deficiencies. First, the boundary conditions for the alluvium are not well known; that is, the thickness of alluvium is known at only a few locations along the major floodplains. Second, insufficient data are available from which to construct water-level contour maps and thus determine flow patterns; that is, only a few wells have been drilled to tap alluvium beneath the major floodplains. Third, no aquifer tests have been been reported for wells tapping the alluvium; thus the aquifer characteristics are unknown. Lastly, water quality data are sparse for the alluvium, also because of the few wells. In addition, these data are quite variable. Southam Canyon has the greatest density of alluvial wells in the project region, but water quality data were reported for only one well.

Unita and Green River Formations--

The Uinta Formation is largely uncharacterized. Fractures are expected to be the major flow paths within the Uinta Formation. No data are available at this time on the location or extent of such fracturing. In addition, the Uinta Formation is probably saturated near the White River. The presence, extent, and characteristics (e.g., transmissivity and gradient) of this zone and its interaction with the deeper Bird's Nest Aquifer are unknown. This zone and the Green River Formation above the Bird's Nest Aquifer could be of central importance as a route of pollutant mobility, particularly in light of likely modification of the hydrogeology as a result of subsidence over the mine zone and filling of the White River reservoir adjacent to Tracts U-a and U-b. For these reasons, the Uinta formation and the Green River Formation above the Bird's Nest Zone require further analysis and characterization.

Bird's Nest Aquifer--

Numerous observation wells have been installed in the Bird's Nest Aquifer throughout the tracts. In general, the density of wells is suitable on a regional basis except for two locations. The first is along the south boundary of Tract U-a. The second is the area across the White River north of Tracts U-a and U-b. Additional data in these areas would provide information on subsurface geology, water levels, aquifer characteristics, and groundwater quality. Data on subsurface geology, water levels, groundwater flow, and groundwater quality are adequate for the existing wells on a regional basis. However, aquifer tests have been reported for only three wells (P-1, P-2, and P-3); thus data on aquifer characteristics are sparse. Because of the small casing diameter on most existing wells, construction of new wells would be necessary to allow aquifer testing. The types of casing used (steel) may also limit determinations of the trace metal and organic chemical content of the groundwater. Lastly, suitable sampling procedures for water from wells have not been established, and optimal sampling frequencies have not been defined.

Douglas Creek Aquifer--

Two wells (P-4 and G16A) have been drilled into the Douglas Creek Aquifer. Since this formation was indicated to be potentially a significant aquifer, additional drilling may be appropriate to ascertain the (1) subsurface geology; (2) water levels; (3) aquifer characteristics; and (4) water quality. Any hydraulic connection of this zone with the Bird's Nest Aquifer has not been clearly established.

Infiltration

Infiltration is the key process in the production of leachate from wastes deposited in the processed-shale disposal area and movement of pollutants into the alluvium or Uinta Formation. Limited data on the infiltration potential of native soils were collected during the environmental baseline studies. Knowledge of the potential for infiltration into the Uinta Formation through fractures is less complete. Potential for infiltration into the processed-shale pile during construction and after completion has been evaluated (Slawson, 1979), but appreciable uncertainties exist with regard to this predictive analysis concerning:

- Infiltration before final compaction, sealing, and stabilization of the disposal pile
- Infiltration potential created by revegetation efforts:
    - Irrigation or leaching of surface layer of process shale
    - Infiltration through revegetation trenches during water harvesting
    - Longevity of surface sealants
- Infiltration during and following short-term, intense precipitation events and during snow melt.

Pollutant Mobility

The rationale for the proposed groundwater monitoring plan (White River Shale Project, 1976) is that the sampling sites designated will provide information on aquifer zones both upstream and downstream from the spent-shale pile. The constituents to be analyzed are identified as either basic indicators of water quality or potential contaminants from processed shale. Water-level monitoring is intended to measure changes in groundwater storage and flow (rate and direction). With the exception of several planned alluvial wells, the existing network of wells is intended to be used for monitoring.

In general, the White River Shale Project proposes no source monitoring, vadose-zone monitoring, or direct determination of infiltration potential. The rationale is that sampling of wells alone can provide adequate information. However, because of the long travel times of percolating water in the vadose zone and saturated zone, decades may elapse before pollutants reach wells. In addition, in order to adequately interpret water quality data from wells, the entire sequence of events from infiltration at the land surface to the well discharge must be understood.

Spent-Shale Pile--

One of the key issues in the environmental evaluation of spent-shale disposal is the potential mobility of pollutants within the shale pile. Such mobility is a function of several factors:

- Retorting processes
- The physical characteristics of waste placement (wetting, compaction), purposeful leaching, permeability, cracking, etc.)
- Water application (e.g., precipitation, irrigation)
- The chemical environment with the spent-shale pile
- Biological activity, including microbiological activity and revegetation.

A need to monitor the moisture status and water quality within the spent-shale pile itself is indicated. The proposed sampling program is deficient in this regard.

Existing Vadose Zone--

The proposed monitoring effort focuses on saturated mobility within the alluvium. Since unsaturated flow may be an important mobility process in the alluvial system of Southam Canyon, Uinta Formation, and the Green River Formation, a need for monitoring this process exists.

Saturated Zone--

Pollutant mobility monitoring in the saturated zone can be broken into indirect methods and direct sampling methods. The proposed monitoring does not include the use of indirect methods such as surface resistivity techniques to trace movement of high-salinity water in the alluvium. Direct sampling from wells is emphasized.

The proposed sampling of water from wells is considered inadequate in several regards: (1) well location; (2) well construction; (3) sampling procedures; and (4) sampling frequency. For the Phase II spent-shale pile, there would be sufficient coverage for the alluvium if additional downgradient wells are installed. However, there are no wells tapping the Bird's Nest Aquifer or Douglas Creek Aquifer in an upgradient or downgradient direction in close proximity to the shale pile. For the Phase III and IV pile, no upgradient alluvial wells have been specified. Again, upgradient and downgradient wells in the Bird's Nest Aquifer and Douglas Creek Aquifer may not be sufficient in number. There is only one existing well tapping the Bird's Nest Aquifer upgradient of the proposed pile and one well downgradient. There are no wells tapping the Douglas Creek Aquifer near the spent-shale pile.

The primary limitation with existing wells for water quality sampling is the small diameter of the casing. For "P" wells, reported casing diameters are:

P-1	2.5-inch

P-2	4.5-inch (pilot hole)
P-2	1.5-inch (core hole)
P-3	4.5-inch (core hole)
P-3	8.0-inch (pumping hole)
P-4	4.5-inch.

For "G" wells, 4-inch casing was reportedly used. If submersible pumps are selected for water sample collection, a minimum 4-inch casing is necessary. If some of the deeper holes are not straight, even this diameter will be too small. Steel casings were apparently used for all monitor wells. The use of steel casing may render the wells unsuitable for sampling for trace metals and organic chemicals because of the possible adsorption of these constituents on casing-corrosion products. PVC would be preferable to avoid such adsorption, but it may lack strength.

Water samples have been collected from wells on the tracts by numerous methods in the past. Bailing, using an airlift, and pumping for different time periods may provide water of different chemical quality from the same well. Cost (of well construction and labor), as well as capability of collecting representative samples, are the key decision factors for selection of sampling method. An additional complication for wells tapping the deeper aquifers on the tracts is that gas is produced with the water. Upon escape of gas from the water sample, changes in chemical composition of the water are likely to occur. In order to successfully monitor groundwater pollution, a uniform method of collecting water samples from wells must be established. Sampling frequencies have been somewhat arbitrarily chosen. Such frequencies may be best determined by frequent sampling for the first year or so of the monitoring program followed by an analysis of constituent variability.

Analysis--

Another key consideration is the selection of the chemical constituents to be sampled. The inorganic constituents included in the White River Shale Project program generally encompass those given highest or intermediate ranking in the preliminary priority ranking (Tables 2-1 and 2-2). Exceptions include certain trace metals, such as zinc, cadmium, and nickel, which may be of intermediate importance. In addition, measurement of carbonate and bicarbonate provides a better characterization of water quality than the total-alkalinity determination proposed by White River Shale Project. Organic analysis in the White River Shale Project program is restricted to general measures--total organic carbon and total carbon. Dissolved organic carbon analysis may be preferable to these measures. Although these measures provide a general screening of organics, a more detailed characterization may be warranted, particularly if changes in gross organic levels are observed in groundwater samples.

It is not clear that analytical work has been documented as to sample collection techniques, preservation of samples, laboratories used, methods of analysis, and quality control procedures. Applicable quality control and quality assurance procedures should include duplicate sampling, using standards for checking analyses, spiking or blink reference samples, calculating cation-anion balances, comparing total dissolved solids content (residue determinations), and other data checks.

Summary of Monitoring Deficiencies

The preceding paragraphs have provided a discussion of data deficiencies and uncertainties that exist for monitoring program development in the processed-shale disposal area. Uncertainties exist in information on source characteristics, in details of disposal and other operational plans, in knowledge of the hydrogeologic framework, and in sampling and projecting mobility of potential pollutants. Many tract-operation monitoring deficiencies result from the utilization of existing wells, which were not drilled for the purpose of operational monitoring.

Table 2-3 presents a summary and relative priority ranking of monitoring deficiencies associated with the monitoring methodology steps. The priority ranking shown here is within each methodology step as well as between these information categories. Monitoring deficiencies for each of the methodology steps are listed in order of relative priority or importance for monitoring program development. With regard to trade-offs between methodlogy-step data deficiencies, the table should be interpreted to mean that highest ranked items for one methodology step have relatively greater priority than lower-ranked items for other steps.

ALTERNATIVE MONITORING APPROACHES

Pollutant-Source Characterization

Monitoring deficiencies with regard to pollutant and source characterization include characterization of waste products and definition of details of construction, operation, and disposal procedures.

Indirect Sampling Approaches--

The DDP (White River Shale Project, 1976) stipulates that solid wastes being disposed of in landfills will be routinely inventoried by tract developers. The records to be kept include types, and approximate quantities, of solid wastes, the disposal area being employed, and special provisions for chemical waste disposal. Alternatives for monitoring include compilation and summarization of data collected by the developers and independent inventories of solid-waste types, quantities, and methods of disposal. Options for inventorying include onsite inspection surveys and remote sensing.

Mathematical simulation models are a possible approach for evaluation or prediction of waste-product characteristics. However, mathematical simulation capabilities for evaluating oil shale retorting operations are in a rather embryonic state. The ability to project waste-product characteristics does not exist at this time.

TABLE 2-3. RELATIVE PRIORITY RANKING OF MONITORING AND INFORMATION DEFICIENCIES IDENTIFIED FOR THE SPENT-SHALE DISPOSAL AREA

	Monitoring methodology steps				
Relative priority ranking	Pollutant-source characterization	Water use	Hydrogeologic framework and existing water quality	Infiltration	Pollutant mobility
Highest	Details of disposal and revegetation operations		Measurement of alluvial materials and aquifer characteristics	Infiltration in processed-shale pile	Mobility in processed-shale pile
	Water-solid waste interactions		Presence and characteristics of saturated zones in Uinta Formation and in the Green River Formation above Bird's Nest Aquifer		Mobility in Southam Canyon alluvium
	Solid-waste characterization	Survey of regional water use	Survey fracturing in the Uinta Formation in cleared areas (if any)	Infiltration in fractures in Uinta Formation	Mobility in the Uinta Formation and Green River Formation above deep aquifers
Lowest	Liquid-waste characterization		Aquifer testing in deep aquifers		Effectiveness of confining layers above the Bird's Nest Aquifer

Onsite inventory and inspection of construction and operation are needed for definition of the details of development plans. Many of these factors greatly influence placement of monitoring equipment and planning of monitoring activities in general.

Of additional utility for source characterization is the maintaining of contact with current research and development in oil shale. In this regard contact with the following groups may prove valuable:

- Governmental agencies
  - U.S. Environmental Protection Agency
  - U.S. Department of Energy
  - U.S. Geological Survey
- Research groups
  - Battelle Pacific-Northwest Laboratories
  - Colorado State University
  - Denver Research Institute
  - Lawrence Livermore Laboratory
  - Oak Ridge National Laboratory
  - Texas Tech University
  - TRW
  - University of Colorado
  - University of Wyoming
- Private industry
  - C-b Shale Oil Venture
  - Equity Oil
  - Geokinetics, Inc.
  - Occidental
  - Paraho Development
  - Rio Blanco Oil Shale, Inc.
  - TOSCO

-- Union Oil

-- White River Shale Project.

Direct Sampling Approaches--

Direct sample collection for pollutant-source characterization can be approached in several ways. Alternative approaches for obtaining samples for analysis include the use of pilot or demonstration-scale (semiworks) facilities and onsite collection at commercial-scale facilities. The major shortcoming in the use of pilot-scale studies is the uncertainty in extrapolating results to larger commercial-sized facilities. The detailed nature of difficulties that may be encountered in making this extrapolation have yet to be demonstrated for oil shale operations. However, the monitoring deficiencies defined in the preceding discussion were so designated after making such an extrapolation to the proposed commercial operation.

Onsite information collection at a commercial-sized operation is probably the best source for characterization of sources and potential pollutants. Possible locations of data collection on waste products are the site of generation within the plant and the site of waste disposal. Because waste-product streams are mixed before or during disposal in the processed-shale disposal area, characterization of waste products prior to mixing and disposal is probably preferred. This will provide a capability of identifying the individual source of chemical constituents that may be observed in leachate from the "mixed" source of the processed-shale pile.

Sampling Frequency--

Sampling frequency requirements for pollutant-source characterization are largely determined by the variability of the waste-product characteristics. Such variability will result from variations in raw-shale (feedstock) composition and plant operation conditions. Once a facility is operational and the various "startup" problems are overcome, somewhat steady-state operational conditions may be assumed and waste-product variation will be largely the result of feedstock composition variability.

Maximum "operation variability" can be expected during the initial stages of development Phase II, III, and IV as defined by the White River Shale Project (1976). Hence, maximum waste-product sampling frequency will be required during these initial stages. Once steady-state operation is achieved, sampling frequencies can be decreased significantly. For example, initial sampling may need to be weekly or more frequently (e.g., daily) for some waste streams. Sampling may evolve to semiannually under steady-state operational conditions. Decisions with regard to sampling frequency should be specific for each waste product to be characterized.

Analytical Methods--

In the following paragraphs, analytical approaches for characterizing solid and liquid waste products are identified. There are two opposing forces active in the evaluation of analytical requirements of a monitoring program:

1. Need or desire to minimize effort or cost

2. Need or desire to minimize environmental risk.

The first of these tends to push the monitoring effort to zero, the obvious minimum-cost state. The latter tends to force the effort to some ill-defined "infinity" level. Obviously some compromise will be developed.

Solid waste-water interactions--This type of analysis deals with measurement of soil-moisture characteristic curves and leachate characterization. These characteristic curves are prepared on solid-waste samples by a method that uses a modified Haynes apparatus. The principles of this method are presented by Day (1965).

Sorption and leachate analyses can be carried out using either beaker (slurry) tests or column tests (using either saturated or unsaturated conditions). Beaker tests are conducted by slurrying a known mass of solid material (e.g., processed shale) with a known volume of liquid (e.g., retort water, distilled-deionized water, or native groundwater or surface water). Chemical analyses of the liquid fraction before and after contact with the solid can provide a rough assessment of mobility or attenuation of various chemical components. Studies using this approach to examine the sorption of various organic fractions on TOSCO-processed shale are reported by Stuber and Leenheer (1978).

Column (or larger scale lysimeter) tests of sorption or leachate production are conceptually similar to beaker tests except that solid-liquid contact is accomplished by the liquid flowing through a column packed with the solid material. Although probably more time-consuming (and costly), column tests can be a more realistic representation of water movement in the processed-shale disposal area and, hence, may provide a more realistic appraisal of potential pollutant mobility. Column experiments can also include unsaturated flow conditions, which are the most likely mode of pollutant transport in the processed-shale disposal area. Unsaturated flow experiments are, however, more time-consuming than saturated flow tests. Such experiments may also include wet-dry cycles to simulate precipitation or irrigation conditions. However, the difficulties in duplicating field conditions in relatively short-term tests are great. Contact times must be long enough to approach equilibrium.

Characterization of solid wastes--Characterization of solid wastes includes analyses of bulk or solids properties and leachate properties. Analyses of solids properties are considered here. Leachates are discussed in the following segment. Analyses of the solid wastes identified in this study as not adequately characterized are summarized in Table 2-4. Types of analysis, the applicability of various analyses to the solid-waste products, information to be gained from the analysis, and cost are the major decision factors.

Characterization of liquid wastes--Analysis options for liquid-waste products identified as being inadequately characterized are presented in Tables 2-5 and 2-6. Criteria for selection of analyses include:

TABLE 2-4. OPTIONS FOR ANALYSIS OF SOLID WASTES CONCLUDED TO BE NOT ADEQUATELY CHARACTERIZED

Analysis	Potential applicability to: Processed shale	Spent catalyst	Water treatment sludge	Spent filters	Type of information obtained from analysis
Particle-size analysis:					Inference of permeability and porosity
– sieving	X	X	X	X	
– hydrometer	X	X	X	X	
X-ray diffraction analysis	X				Identification of clay particles Inference of sorptive properties
Surface area	X				Inference of sorptive properties
Water content:					Inference of general hydraulic properties particularly with regard to unsaturated flow
– 1/2 atmosphere	X				
– 15 atmospheres	X				
– in situ	X				
Bulk density–in situ	X				Inference of permeability and porosity
Base exchange capacity	X				Attenuation mechanisms
Cation exchange capacity	X				Attenuation mechanisms
Hydrous oxides	X				Attenuation mechanisms
Saturated extract analysis	X	X	X	X	Potentially mobile constituents
Beaker–sorption tests	X				Mobility-attenuation evaluation
Column experiments:					Mobility-attenuation evaluation
– saturated flow	X				
– unsaturated flow	X				

TABLE 2-5. OPTIONS FOR ANALYSIS OF LIQUID WASTES, INCLUDING LEACHATES CONCLUDED TO BE NOT ADEQUATELY CHARACTERIZED

Waste product	Potential applicability of analyses[a]: Major inorganics	Trace elements	Organics
Spent shale (leachate)	X	X	X
High TDS wastes	X	X	
Sour water	X	X	X
Retort water	X	X	X
Spent-shale moisturizing mixture	X	X	X
Spent catalysts (leachate)		X	
Water treatment sludge (leachate)	X		
Oily waste water	X	X	X
Spent filters (leachate)		X	X
Mine water	X	X	X

[a] See Table 2-6 for detailed listing of major inorganics, trace elements, and organics analyses

TABLE 2-6. ALTERNATIVES FOR CHEMICAL ANALYSES

Analysis Category	Alternative Analyses
General water quality:	pH
	Eh
	Specific conductance
	TDS
Major inorganics:	Ca
	Mg
	Na
	K
	SO_4
	Cl
	HCO_3
	CO_3
	F
Trace elements:	Se
	As
	Mo
	Zn
	Cd
	Hg
	Ni
	B
Organic analysis:	TOC
	DOC
	COD
	BOD
	DOC-fractionation[a]
	Oil and grease
	Benzene-soluble organics
	Phenolic compounds
	Organic nitrogen
	Benzo (a) pyrene

[a] hydrophilic-hydrophobic, acid-neutral-base

- The existence and accessibility of analytical capability
- Costs (including sample collection, handling, and laboratory analysis)
- The information to be obtained from the analytical data (i.e., approaches to interpret the data must exist).

A preliminary study dealing with data interpretation is presented in Appendix C.

Inorganic chemical sampling requirements for the spent-shale disposal area are readily identifiable from the results presented in Table 2-1. Monitoring based on the three evaluation criteria discussed above is expected to include:

- Basic or general water quality measures such as pH, specific conductance, and total dissolved solids concentration
- Major inorganic constituents (Ca, Mg, Na, K, SO_4, Cl, HCO_3, CO_3, F, N (compounds, etc.)
- Selected trace constituents (Se, As, Mo, Zn, Cd, Hg, Ni, B).

These constituents include the measures commonly used to evaluate the quality of waters used for domestic, agricultural, and industrial purposes. Thus, the interpretation of monitoring data obtained with regard to water use would be somewhat straightforward using available water quality standards and criteria. In addition, analytical procedures for these constituents are readily available, are widely accepted, and are relatively inexpensive. Some caution should be exercised with regard to the use of standard analytical procedures for analysis of raw process waters. For example, studies by Fox et al. (1978) concluded that standard analytical methods cannot be used for many water quality parameters in such complex waters. Instrumental methods produced more accurate results because fewer interferences were encountered than with chemical methods. General recommendations and conclusions (from Fox et al. (1978)) included:

- Extensive methods development work is needed for analysis of cyanide, chemical oxygen demand (COD), phenols, orthophosphate, solids, and sulfide in process waters
- Existing methods for sulfate, inorganic carbon, and some sulfur species may be adequate, but more testing should be conducted
- Of the instrumental methods evaluated, spark-source mass spectrometry produced the lowest detection limits but the poorest precision; X-ray fluorescence and neutron activation and analysis produced precise and accurate results; and atomic absorption spectroscopy was acceptable for analysis of Ca, Mg, Fe, Na, Si, As, K, Se, and Zn.

Sampling and analysis of radiological constituents is also a monitoring option. Constituents to be considered include radium-226, radium-222, radionuclides of uranium, thorium and potassium, alpha activity, and beta activity. Lee et al. (1977) provide a summary of potential radioactive pollutants for oil shale, coal, potential geothermal, and nuclear energy industries. Their conclusion was that radiological problems from oil shale operations are expected to be relatively insignificant.

Organic constituent monitoring needs are less well defined than are monitoring needs for inorganics. This situation exists because many organic wastes are not completely characterized quantitatively or qualitatively, the mobility of the various constituents is not well understood, and the potential deleterious effects of organic components in oil shale wastes are not well known in many instances. These uncertain or unknown factors are key elements addressed in the planning and implementation of the monitoring program.

The spectrum of alternative organic sampling schemes ranges from analysis of specific compounds to analysis of lumped parameters, such as chemical oxygen demand (COD) or total organic carbon (TOC).

In order to address the development of an organic sampling scheme, consider the following analytical approaches:

- Gross measures of organic content, such as
    - COD
    - TOC or DOC
    - Biochemical oxygen demand (BOD)
    - Organic solvent extracts (e.g., carbon-chloroform or carbon-alcohol extracts (CCE or CAE, respectively) benzene-soluble organics)
- General fractionation, such as
    - Hydrophobic-hydrophilic fractions
    - Acid-base-neutral fractionation of hydrophobic and hydrophilic fractions
    - Aliphatic-aromatic fractions
    - Molecular weight fractionation
- Specific fractionation, such as
    - Phenolic compounds

-- Nitrogen heterocyclic compounds (e.g., maleimides, succinimides, carbazoles)

-- Organic acids

- Benzo(a)pyrene

  -- Benz(a)anthracene (1,2-benzanthracene)

  -- 7,12-dimethylbenz(a)anthracene

  -- 3-methylcholanthrene.

The following paragraphs present a brief discussion of the benefits (gain of information) associated with each of these categories. The costs (analytical effort) for these categories generally increase from the gross measures to specific compounds in the order listed previously. Design of a groundwater quality monitoring program must include consideration of not only what is sampled and cost, but the interpretive utility of the information obtained.

The gross measures provide a coarse view of the level of organic material present in samples but provide little information on the characteristics of the compounds included. BOD indirectly measures the biodegradable organics over a given time period at a specific temperature. Although BOD analysis is a standardized procedure, the results are still rather variable and not very sensitive. COD measures that portion of organic matter digested within 2 hours by dichromate acid reagents. However, some inorganic materials are also oxidized, and certain organic compounds, such as straight-chain aliphatics and aromatic hydrocarbons, are not readily oxidized during the COD test unless catalyzed. The TOC test attempts to quantify the organic matter that is converted at high temperature to carbon dioxide. The test is completely nonspecific as to compound type, and no inference as to hazard can be made. This is a shortcoming common also to BOD and COD measures, as well as to the various organic solvent extraction techniques. However, TOC is preferable to BOD or COD as the determination is independent of microbial effects, toxic substances, and variability with diverse organic constituents. DOC analysis shares this advantage and is commonly more precise and accurate than the TOC determination (Baker, 1976).

Sampling programs that include general fractionation procedures would offer some information on the types of organics that are mobile. With this approach, the general character of the organic complex would be identified (e.g., dominance of hydrophobics or hydrophilic acids, etc.), and hence "candidate compound types" could be inferred through the use of information on more detailed source characterization.

The interpretive utility of fractionation data would be greatly enhanced if the potential toxicity, carcinogenicity, etc. were nonuniformly distributed among the various general organic fractions. For example, if hydrophobic bases were extremely carcinogenic relative to hydrophobic acids, then an observation of the increasing dominance of the former fraction would offer more information than if no such toxicological difference existed. Some research (e.g., at Battelle Pacific-Northwest Laboratories, Oak Ridge National Laboratory, etc.) is presently underway to address the potential biological effects of various organic fractions of oil shale wastes. The type of information will clearly enhance the potential utility of fractionation schemes for monitoring. However, the extent to which these data on differential fraction toxicity are process-dependent must also be assessed.

Molecular weight fractionation may also have some potential for use as a monitoring tool. The variation of acute toxicity of organics with molecular weight has been demonstrated for a few classes of compounds (Herbes et al., 1976). Bioaccumulation, another important factor in assessing the potential environmental hazards of materials, may also vary with molecular weight (Herbes et al., 1976).

The analytical costs associated with more specific fractionation are dependent upon the fractions selected. For example, analytical procedures for "phenolic compounds" are relatively inexpensive. Other approaches, which require chromatographic or spectroscopic methods, would be more expensive in general.

The major advantage of analysis of specific fractionation over general fractionation as a monitoring procedure is that much more information is already available as to the potential deleterious effects of many of these compound groups. For example, phenolics have been associated with potential carcinogenic effects of oil shale products (Loogna, 1972). Also, many nitrogeneous organic compounds, such as N-nitroso compounds, hydroxylamines, and hydrazines (Varma et al., 1976), have been labeled as potentially carcinogenic or mutagenic. Thus, specific fractionation data may be more readily useful than the general fraction because of the existence of data on biological effects.

Identification and quantification of specific organic compounds is probably the most expensive of the approaches considered here. Sophisticated instrumentation and sample-handling procedures are usually needed. There are, however, probably several thousand organic compounds to be found in the various waste streams associated with an oil shale mining and retorting operation. Thus, one would have to be highly selective in the choice of compounds for such monitoring to be feasible. In addition, compound-specific data on biological effects would be required for the data to be useful.

The spatial and temporal layout of the monitoring program will be designed to identify the presence, extent, and rate of pollutant mobility. One of the key criteria in the selection of the chemical analytical program is its potential for interpreting environmental hazard. This hazard can be a use limitation for domestic, industrial or agricultural use, an increased treatment requirement for these uses, or related biological "harm" categories of toxicity, carcinogenicity, teratogenicity and mutagenicity.

Except for a few selected pesticides and halogenated hydrocarbons, water quality standards have not been promulgated for organic constituents. Only a few criteria have been proposed. The desire to use monitoring data to infer potential environmental hazard creates a possible role for direct measures of impact potential. Options include general toxicity, bioassay procedures, such as fish or mammal toxicity, or more specific procedures, such as the Ames assay (a cell-culture technique using a specific strain of Salmonella) or other cell-culture techniques. The monitoring approach using these techniques would include field collection of samples and the use of these samples in bioassay tests.

An advantage of such a monitoring program is the direct inference of potential effects without the need for detailed chemical characterization. Disadvantages are that some approaches are time-consuming and, thus, expensive (some cell-culture techniques are, however, fairly rapid--a few days). Also, questions of dosage used and the interpolation of results to real-world (e.g., human) exposure must be addressed. These types of tests are, however, presently being used for environmental screening of chemicals. Their utility for monitoring purposes deserves consideration.

Water Use

Water use patterns in the project area play an important role in determining monitoring needs. This is because "pollution" can only be defined relative to restrictions or limitations placed on various water uses by water quality factors. Individual oil shale facilities will be operating for periods of several decades; waste products, such as processed shale, will be present as potential pollution sources indefinitely.

Water use patterns must be periodically reevaluated to assess the extent to which changes in water use may be affected by oil shale development. Sources of information for the Tracts U-a and U-b region include:

- Uinta County government
- State governmental agencies (e.g., Water Quality Bureau, Natural Resources Department--Water Rights and Water Resources Division)
- Local governmental units (e.g., Vernal, Bonanza, Ouray)
- Federal Governmental agencies (e.g., U.S. Geological Survey, U.S. Bureau of Reclamation, U.S. Bureau of Land Management)
- Uinta and Ouray Indian tribes
- Major industries (e.g., American Gilsonite, White River Shale Project).

Phone or mail surveys may be conducted on an annual or biennial frequency to obtain water use data. Direct compilation of records of the above data sources by monitoring program personnel can also be employed. Although more effective than indirect (i.e., phone or mail) contact, costs would be greater.

Hydrogeologic Framework and Existing Water Quality

Portion of the System to be Monitored--

As previously noted, certain data deficiencies exist with regard to the hydrogeologic characteristics of the area soils, alluvium, the Unita Formation, the Green River Formation above the Bird's Nest Aquifer, the Bird's Nest Aquifer, and the Douglas Creek Member (in the Green River Formation). Thus, certain aspects of all portions of the hydrogeologic system of the project area are included in the following discussion.

Alternative Approaches--

Alluvium and watershed characterization--To address the previously identified data deficiencies, studies should be conducted in Southam Canyon to determine thickness, areal extent, and physical-chemical properties of the alluvium, and the presence and nature of saturated zones. Studies may include a drilling program for the collection of drill cuttings and preparation of lithologic logs, and for characterizing the depth to bedrock (the Uinta Formation). Observation wells may be installed to supplement existing wells. Holes from the drilling program can be used for installation of equipment to monitor the moisture status of the alluvium. Alternatives include: (1) neutron soil-moisture logging; (2) tensiometers; (3) soil-moisture blocks; (4) thermocouple psychrometers; and (5) salinity sensors. These installations may be used to characterize baseline moisture conditions within the alluvium and to monitor water-content changes during operation.

Seismic refraction and gravity surveys could be utilized to more accurately determine the subsurface extent of the alluvium in Southam Canyon and the White River. This information would be useful for selection of drilling sites for monitor wells and for interpretations of aquifer test results. For example, in some areas it is not known at present if saturated alluvium is present. These surveys would also be necessary to allow successful use of surface resistivity surveys to trace the movement of saline water in the alluvium.

Additional monitor wells may be constructed in the alluvium of Southam Canyon. Such wells will allow collection of additional information on lithology of the alluvium, such as by geologic logging during drilling. Second, they will provide additional points of measurement for water levels and a determination of groundwater flow patterns. Third, if constructed prior to operation, they will provide additional information on the quality of groundwater in the alluvium under undeveloped conditions. Construction of the proposed monitor wells may thus remedy a number of present deficiencies in knowledge of the hydrogeologic framework of the alluvium. If alluvial material is removed before construction of the disposal pile, surface fracturing in the underlying Uinta Formation could be mapped.

Runoff in on-tract and off-tract watersheds, potentially creating ponding conditions behind the spent-shale pile, can be estimated via a suitable model. Examples of alternative runoff models include:

- Soil Conservation Service (SCS) method
- Rational formula
- Infiltration indices method
- Hydrograph methods
- U.S. Geological Survey (USGS) regional drainage and general characteristic methods.

The rainfall-runoff characteristics for various segments of the processed-shale disposal area may thus be estimated. The White River Shale Project has employed the SCS and USGS methods.

Physical-chemical characterization--Drilling or coring programs can be conducted to obtain samples of soils, alluvium, and geologic materials in the processed-shale disposal area. Options for physical-chemical characterization of these materials are the same as previously listed for solid-waste materials (Tables 2-4 and 2-5). Samples may be collected for particle size analysis, moisture content, base and cation exchange capacities, and other physical-chemical characteristics, including development of soil-moisture characteristic curves and other hydraulic properties. Beyond parameter sampling alternatives, optional spatial configurations (grid size and depth) for sampling of these characteristics also may be proposed.

During aquifer tests or at existing wells (where possible), evaluation of water quality sampling procedures can be accomplished. For example, waters can be frequently sampled during pumping to aid in determining appropriate sampling procedures for future water quality monitoring and to assess data collection during baseline studies by bailing wells or using thief samplers. This sequential sampling during pumping can include field measurements (such as pH, conductivity, or specific ion electrodes) or periodic collection of water samples for more detailed chemical analyses.

Aquifer Characterization--Aquifer tests can be conducted in saturated sections of the alluvium, the Bird's Nest Aquifer, and the Douglas Creek Aquifer.

Alluvium--A number of aquifer tests could be conducted on alluvial monitor wells (existing or new). The small diameters of existing wells may prohibit proper aquifer testing. Larger diameter (perhaps 6- or 8-inch) casing may be needed for new monitor wells to be tested. The casing size should allow installation of a suitable submersible pump, as well as an access tube to permit water-level measurements during pumping. Aquifer tests may be conducted in the following areas:

- Southam Canyon (Phase II), below the retention reservoir and upstream from the retention reservoir, along the main drainage
- Southam Canyon (Phases III and IV), upstream of the retention dam, downstream of the spent-shale pile along the main drainage,

downstream of the spent-shale pile along the tributary to the main drainage, and upstream of the spent-shale pile along the main drainage.

Existing wells would be useful as observation wells for these tests. For example, it may be advisable to determine aquifer parameters near the confluence of Southam Canyon and the White River. This would require installation of a new alluvial well with a larger diameter casing than existing wells. Such a well could be placed near existing well AG-6 or G-1A. One of these wells could be used as an observation well during aquifer testing.

In all cases, discharged water should be piped a sufficient distance away from the pumped well and observation wells so as not to adversely affect the aquifer test results. A suggested period of continuous constant discharge pumping for alluvial wells is 24 hours (if possible). The appropriate pumping rate would be determined during the initial stages of the aquifer test. Drawdown and recovery water-level measurements should be made and discharge carefully measured as a basis for determination of aquifer parameters.

Uinta and Green River Formations--Characterization of the Uinta Formation and the Green River Formation above the Bird's Nest Aquifer should emphasize evaluation of fracturing in the Uinta Formation and of the suspected saturated zones near the White River. Surface fracturing in the Uinta Formation may be assessed in areas cleared of alluvium or soil cover. Test drilling near the mouth of Southam Canyon would be needed to identify and characterize saturated zones in these two formations above the Bird's Nest Aquifer. Sufficient wells (e.g., three) should be installed to determine gradients and groundwater flow patterns.

The evaluation of hydraulic interconnection between the White River and the Bird's Nest Aquifer should be part of this study element. This would also provide a basis for assessment of modification of the hydrogeologic system from subsidence or White River reservoir development.

Bird's Nest Aquifer--Numerous additional monitor wells may be proposed for the Bird's Nest Aquifer near the spent-shale pile. As for the alluvium, these wells would allow collection of supplemental data on subsurface geology, water levels, and water quality. The variability of available data results in significant uncertainty with regard to the hydrologic characteristics of the aquifer beneath the spent-shale disposal area. Thus, the present site-specific knowledge of the Bird's Nest Aquifer could be greatly expanded.

Aquifer tests have been conducted on three wells tapping the Bird's Nest Aquifer. The small diameter of existing wells virtually prohibits proper aquifer testing. Relatively large-diameter (e.g., greater than 8 inches) casing is preferred for monitor wells to be tested. Additional aquifer tests may be needed in the following areas:

- Southam Canyon (Phase II), upgradient and downgradient of the spent-shale pile

- Southam Canyon (Phases III and IV), upgradient and downgradient of the spent-shale pile.

Proper aquifer test procedures should be followed as for alluvial wells. In this case, existing wells in the Bird's Nest Aquifer could be used as observation wells. The recommended period for aquifer testing of wells in the Bird's Nest Aquifer is one week.

As previously mentioned, new wells across the White River north of the tracts would provide a better indication of the relation of groundwater in the Bird's Nest Aquifer to that in the alluvium. From a strictly hydrogeologic point of view, good locations include the SE1/4 Section 8, T10S/R24E, and near the center of Section 10, T10S/R24E. Practical considerations such as access would, of course, influence the exact location. These wells should be equipped with casing sufficient to allow aquifer testing.

Douglas Creek Aquifer--Numerous additional monitor wells may be proposed for the Douglas Creek Aquifer near the spent-shale pile. These wells would allow collection of supplemental data on subsurface geology, water levels, aquifer characteristics, and water quality, which are not available for the Southam Canyon disposal site. Presently, there is only one well (P-4) tapping the Douglas Creek Aquifer for which this information is available.

Because only one well has been tested, new monitor wells would need to be constructed with sufficiently sized casing (e.g., greater than 8 inches) to allow aquifer testing in the following areas:

- Southam Canyon (Phase II), upgradient and downgradient of the spent-shale pile

- Southam Canyon (Phases III and IV), upgradient and downgradient of the spent-shale pile.

Proper aquifer test procedures should be followed as for alluvial wells. In this case, existing wells in the Bird's Nest Aquifer and Douglas Creek Aquifer could be used as observation wells. The recommended period for aquifer testing in the Douglas Creek Aquifer is one week.

Sampling Frequency--

Many of the characterization efforts discussed in the preceding paragraphs are single-time studies. Examples of this type of survey include description of alluvium cross sections, analysis of physical-chemical characteristics of soils, alluvium and other geologic materials, and aquifer testing.

Monitoring of moisture content, water levels, and water quality are likely to be ongoing studies that are eventually incorporated into pollutant source monitoring programs. Moisture-content monitoring frequency would be best determined after an initial set of observations under natural or experimental conditions have been made (see following discussions of infiltration and pollutant mobility monitoring). In a system not heavily pumped, the quarterly sampling presently proposed (White River Shale Project, 1976) may be adequate if not excessive. Changes in area water use or need for mine dewatering may affect pumping of the Bird's Nest Aquifer and should be considered in periodic reviews of the monitoring program.

Determination of groundwater quality monitoring frequency is dependent upon the results of the pumping versus bailing evaluation. If sampling by bailing has not biased the results obtained during the baseline period, then frequencies proposed by the tract developers (quarterly for alluvial systems and semiannually for the Bird's Nest Aquifer) may be appropriate. If bailing is not an adequate sampling procedure, then an appropriate sampling frequency both for baseline characterization and for operational monitoring will have to be developed.

Analytical Methods--

Analysis procedures for soils, alluvial, and other geologic materials are as previously outlined for solid-waste characteristics (Tables 2-3 and 2-4). Water quality analyses presented in Table 2-6 are also applicable to characterization of groundwater quality in the alluvial and deep aquifer zones associated with the processed-shale disposal area.

Infiltration

Portion of the System to be Monitored--

Infiltration can be studied for the surface of the processed-shale disposal pile, landfills of other materials, the alluvium of Southam Canyon, and the bedrock under the disposal area. The Phases III and IV processed-shale pile abuts the southern boundary of Tract U-a. Upstream drainage in Southam Canyon may become impounded behind the disposal piles leading to leachate production. Monitoring of the Uinta Formation (indigenous vadose zone) in the disposal pile area could be at locations developed during the hydrogeologic studies outlined in the preceding discussions.

The processed-shale pile constitutes an extension of the indigenous vadose zone. When completed, the pile will be 500 feet high, so that the entire vadose zone will be about 1,100 feet in thickness (Slawson, 1979). Since infiltration potential may change with the progress of development, infiltration into the pile may need to be evaluated during construction or upon completion. Water movement into soils within trenches used for revegetation may also be monitored.

Particular attention should be paid to monitoring within the sloping faces of the disposal pile, particularly in the regions at lower elevation near the natural land surface. It is in these regions that leachate will most likely be generated during flooding for salinity control and during water harvesting. For example, using a water-balance approach, it has been estimated that if 5 feet of water is applied for salinity control about 30 to 40 feet of underlying shale would be moistened to field capacity. On the sloping face, excess water at elevations less than 30 to 40 feet above the base of natural ground surface would be available to saturate the spent shale, leading to leachate production. Similarly, during water harvesting, water has been projected to move about 10 feet below the trenches. These estimates of infiltration are for average conditions; the effect of, for example, a series of wet years is uncertain although leaching would clearly be enhanced.

The Uinta Formation is composed of dense, fine-grained sandstone interbedded with thin claystone layers. Near the surface, weathering has created a softer, more permeable zone. It is expected that because of low porosity of the sandstone it will not transmit large volumes of water. However, numerous deposits of evaporite salts on outcrops of the Uinta Formation have been noted along the White River. These salts accumulate on exposures of the claystone interbeds, indicating that meteoric water has moved down through the sandstone and then down-dip along claystone bedding planes. In addition, the Uinta Formation is cut by large but infrequent fractures and joints. These fractures might conduct water down toward the underlying Bird's Nest Aquifer or, if they close at depth, horizontally toward the White River. Subsidence from mine operations may result in more extensive fracturing within the Uinta Formation.

Because of the heterogeneous nature of the Uinta Formation, the monitoring programs need to be specifically designed for this situation. Sensors or sample collection devices would have to be located in those specific locations where percolating water might occur. In order to facilitate this process of location, several research efforts, as outlined below, would be helpful.

Infiltration and lysimeter studies, such as those discussed herein, may be very useful in isolating pathways of groundwater movement, such as fractures, bedding planes, clay layers or the interface between weathered and unweathered sandstone, if these features are present or in close proximity to the test sites.

Alternative Approaches--

Infiltration processes in the spent-shale disposal area can be examined through direct water-application/moisture-mobility monitoring tests or through monitoring of water mobility resulting from natural precipitation. Approaches for preliminary testing of infiltration potential are discussed here. Alternatives for monitoring water movement in the actual spent-shale disposal area are presented in subsequent discussions of alternatives for monitoring pollutant mobility.

Infiltration simulation studies may be conducted on alluvium, bedrock, or spent oil shale using double-ring infiltrometers. Rainfall simulators may also be employed. A sufficient number of locations should be selected to overcome errors introduced by spatial variability of infiltration properties. Results of such tests may be presented by plotting on a base map of the tract area.

Infiltrometer studies may be conducted at several sites on the spent-shale pile, during construction and after pile completion, to determine representative intake rates. In addition, values from long-term infiltration tests can be used to estimate hydraulic conductivity. Infiltration studies can also be conducted as part of lysimeter studies and will be outlined later as an alternative approach for evaluating pollutant mobility.

Sampling Frequency--

Because the rates of subsurface water movement in the processed-shale disposal area are not well known at present, sampling frequencies for various moisture monitoring activities cannot be defined in detail. Sampling frequency should be based on observed rates of change in moisture level in various parts of the natural subsurface and the waste disposal pile. Thus, the appropriate sampling frequency may vary with seasonal or operational (e.g., irrigational changes). Infiltrometer or lysimeter studies can be helpful in determining hydraulic conductivity rates and thus in assessing sampling frequency requirements.

Pollutant Mobility

Pollutant mobility monitoring deals with detecting and measuring the movement of chemical constituents in the subsurface. These monitoring efforts are closely interrelated with infiltration and subsurface water movement monitoring.

Portion of the System to be Monitored--

Possible locations for monitoring pollutant mobility include: the land (or disposal pile) surface; unsaturated or saturated layers within the processed-shale disposal pile and separate landfill sites; the alluvium of Southam Canyon; within the Uinta Formation; Green River Formation above the Bird's Nest Aquifer; the Bird's Nest Aquifer; and the Douglas Creek Member. Mobility monitoring within the spent-shale disposal pile may be addressed during pile construction (spreading, grading, and compaction), during leaching of surface layers to remove salts, within and below soil trenches during water harvesting, and within the toe of the spent-shale pile.

Alternative Approaches--

Processed-shale pile--Laboratory testing, field testing, and monitoring of actual disposal operations are the basic options for evaluation of pollutant mobility for the processed-shale disposal pile. Many of the methods discussed for infiltration monitoring may be used to infer movement of potential pollutants. Visual surveys of landfill and the processed-shale pile areas can also be conducted to observe the presence of runoff or seepage. Small weirs can be installed to meter flows if they occur.

Remote sensing techniques may be used to monitor snow cover and perhaps soil moisture on the tracts, to determine the growth and aerial location of the spent-shale pile, and to detect the presence of leachate and waste-water flow in washes.

Laboratory testing--Column experiments such as previously described can be used to obtain leachate breakthrough curves. Columns filled with spent-shale samples moistened with various waste waters would be flooded with deionized water. Methods suggested by Phillips (1977) can be used in an attempt to identify specific water sources in elutriated samples from columns moistened with blended waste waters (see Appendix B). Such experiments would be useful for the development of data evaluation approaches for the monitoring program.

As indicated for infiltration monitoring program development, laboratory studies are necessary to determine the effect of high salinity levels in spent oil shale on the functioning of equipment used for obtaining soil water samples and for measuring soil water pressure. For example, "salt sieving" may occur across ceramic cups used to extract water samples during unsaturated flow (Nielsen et al., 1974). Consequently, salinity in extracted samples may be lower than actually present in the pores of the surrounding media. Another possible difficulty in the operation of ceramic-cup samplers is that salts may be adsorbed or may precipitate within the pores.

If solute is somehow restricted by the porous media (i.e., the spent shale), water movement may occur in response to osmotic pressure gradients in addition to hydraulic gradients. Tensiometers, used to measure soil water pressure, will not reflect osmotic gradients, and therefore estimates of soil water flux will be in error. Such effects are expected, however, to be minor. In addition, the operation of tensiometers may be affected by differences in solute concentrations between the inside of the tensiometer cup and the soil solution.

The operation of other instruments such as salinity sensors, moisture blocks, and psychrometers may be markedly affected by high salt levels. For example, thermocouple psychrometers operate on the principle of a relationship between soil water potential and relative humidity of soil water. High salinity levels will affect the vapor pressure of soil water and, hence, the relative humidity.

Laboratory (or field) studies can be conducted to determine the effect of salt sieving at the air-water interface on evaporation rates from spent shale. As discussed by Nielsen et al. (1974), the air-water interface behaves as a perfect semipermeable membrane. Solutes concentrate at the surface, reducing the vapor pressure of the water and consequently the evaporation rate.

Field testing--Several sites should be selected to measure moisture flux in spent shale using methods reported by Nielsen et al. (1974) and Bouwer and Jackson (1974). These methods require using tensiometers and moisture logging in test basins to determine unsaturated hydraulic gradients and water-content changes. Test basins are flooded until an instrumented depth of underlying spent shale is brought to near saturation. The basins are covered with plastic to reduce evaporation, and records are obtained of tensiometer and moisture-logging data. This technique is also useful in determining the areal distribution of hydraulic parameters of the spent-shale disposal pile. These studies would be integrated with investigations on the flux of solutes. Results of these onsite studies can be correlated with those from similar studies conducted in lysimeters.

Onsite lysimeters can be constructed to simulate water and pollutant movement within the vadose zone. This procedure also allows the testing of sampling devices under field conditions. Possible lysimeter tests include: (1) spent shale overlying Southam Canyon alluvium; (2) spent shale overlying bedrock; (3) solid waste (e.g., garbage) overlying alluvium; (4) solid waste overlying bedrock; and (5) spent shale overlying other solid wastes and alluvium or bedrock.

Lysimeters can be of various designs. For example, wooden boxes approximately 10 x 10 feet and several feet high can be constructed directly above alluvium or bedrock sites. For alluvium sites, lysimeter walls should extend several feel below the land surface. The inside walls of the lysimeters should be lined with plastic or butyl rubber to eliminate side flow.

The aboveground portion of the lysimeter is backfilled with test material (e.g., spent shale or garbage). These materials should be moistened and compacted to simulate, to the extent possible, waste-disposal conditions within the spent-shale disposal area. Lysimeters can be variously instrumented with water-sampling devices, such as suction-cup lysimeters, salinity probes, or small-diameter wells or piezometers. Equipment to monitor water content or soil water pressure includes tensiometers, psychrometers, moisture blocks, and access wells (for neutron moisture logging). Access wells should be installed to the total depth of the lysimeter. Other devices may be installed at various depths.

Moistened spent-shale samples can be obtained by test boring in lysimeters or in the processed-shale disposal pile. Laboratory analyses of these samples should include water content, soluble salts, electrical conductivity (EC) of the saturated extract, etc. These data can then be correlated with in-situ neutron moisture logs, salinity sensor data, etc. to evaluate and calibrate these monitoring techniques.

Adjunct studies can be conducted on the lysimeters, including determination of the relationship between tritium levels in natural rainwater and in cores taken in depthwise increments within the spent shale. Comparison of tritium profiles in the spent shale with precipitation input of tritium would provide a measure of the actual infiltration of precipitation. The use of this technique for examination of recharge in semiarid regions and for tracing the movement of groundwater pollutants is discussed by Smith (1976).

Operational studies of monitoring equipment can also be conducted in conjunction with lysimeter studies. These studies will determine operational difficulties of using various types of sampling equipment (suction-cup lysimeters) and other monitoring gear, such as neutron moisture loggers, tensiometers, and moisture blocks in the spent-shale disposal area.

Monitoring in landfill--Depending on the results of the lysimeter studies, the following units may be installed in cover material between cells (individually covered units) within landfills during construction: access wells, tensiometers, moisture blocks, thermocouple psychrometers, and salinity sensors. These units would then be monitored to detect the flow of water and salts within solid waste and cover material of the landfills. Similar units could also be installed in allumium or bedrock underlying the landfill. During construction of the landfills, and later as the landfills become enveloped by spent shale, care will be taken to add additional tubing or casing to permit accessing the units. The cooperation of operators of earth-moving equipment will be required to avoid damage to these units. An alternative that minimizes potential interference with disposal operations is to install suction-cup lysimeters, moisture blocks, etc. in a horizontal array rather than in a vertical array (via vertical access tubing) as outlined above.

Monitoring in the processed-shale pile--During construction of the spent-shale pile, access wells may be drilled into the pile and underlying Uinta Formation and monitoring via a neutron moisture logger (see Figures 2-2 and 2-3). It should be noted that the disposal-pile concept shown here is as described in the Detailed Development Plan (White River Shale Project, 1976). Alternatives include stockpiling of alluvium before pile construction for later use as soil cover on the disposal pile. Additional wells may be installed in the alluvium channel downstream of the advancing pile, within the pile at the upstream face, and within the downstream foot of the pile to include monitoring of all segments of the disposal pile. As alternatives or additions to neutron logging, moisture blocks, salinity sensors, and thermocouple psychrometers can also be installed within the spent-shale pile. Both the access wells and accessories for other units will be added as the elevation of the pile increases. This need may be overcome to some extent by a horizontally oriented array of sensors.

Access tubing may also be logged to determine the development of saturated or near-saturated zones. Access wells completed in saturated zones could be used for collection of neutron moisture logs, temperature profiles, water levels, and water quality samples. Note that the saturated zone would provide moisture calibration. Particular attention should be paid to the interfacial region between the spent shale and native soils, allumium, or bedrock. Data from thermocouple psychrometers are also helpful in determining water movement. Suction-cup lysimeters are installed in regions suitable for their operation--that is, where the pore water pressure is greater than -0.8 atmosphere (see Figure 2-2). These units may fail as the disposal pile grows. Piezometers can be installed in saturated regions should such regions be observed, for example, at the interface between different lifts or layers of spent shale or between spent shale and native sediments. Piezometers can also be used for neutron logging. Observation wells abandoned by the White River Shale Project, or specially constructed wells, can be used to sample saturated allumium should such zones develop.

As the spent-shale pile expands and increases in elevation, the units installed during early phases of construction will have to be extended upward. Additional suction-cup lysimeters will need to be installed in regions of favorable water pressures (e.g., perched groundwater). In time, it may be necessary to construct wells to house these units, using construction techniques reported by Apgar and Langmuir (1971). In addition, the lowermost units will eventually fail as suction capabilities are exceeded. When the spent-shale pile reaches its final elevation at a given sampling location, the monitoring units should be enclosed in protective shelters to minimize

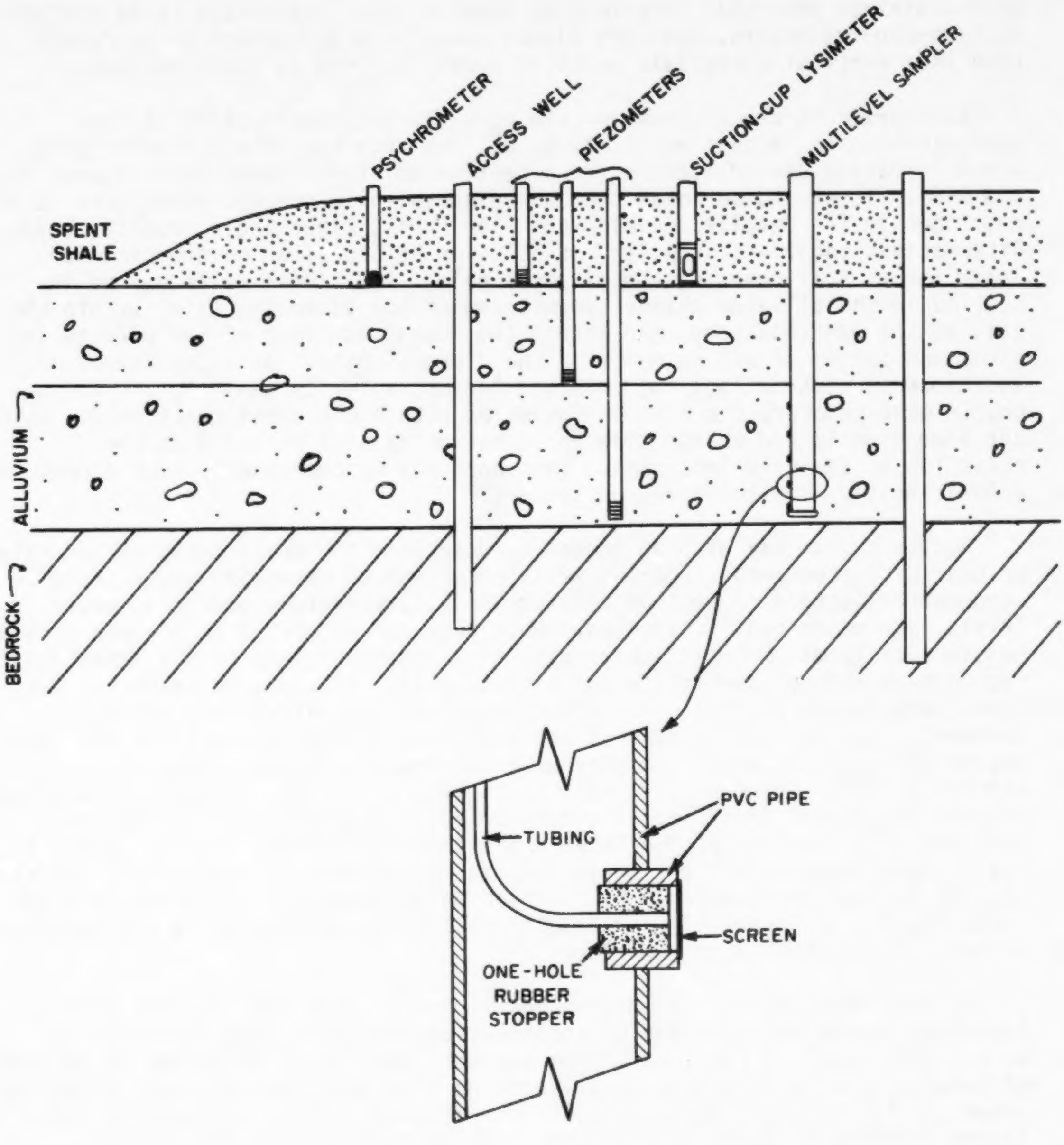

PSYCHROMETER
ACCESS WELL
PIEZOMETERS
SUCTION-CUP LYSIMETER
MULTILEVEL SAMPLER
SPENT SHALE
ALLUVIUM
BEDROCK
PVC PIPE
TUBING
SCREEN
ONE-HOLE RUBBER STOPPER

Figure 2-2. Possible monitoring facilities for spent-shale pile during construction.

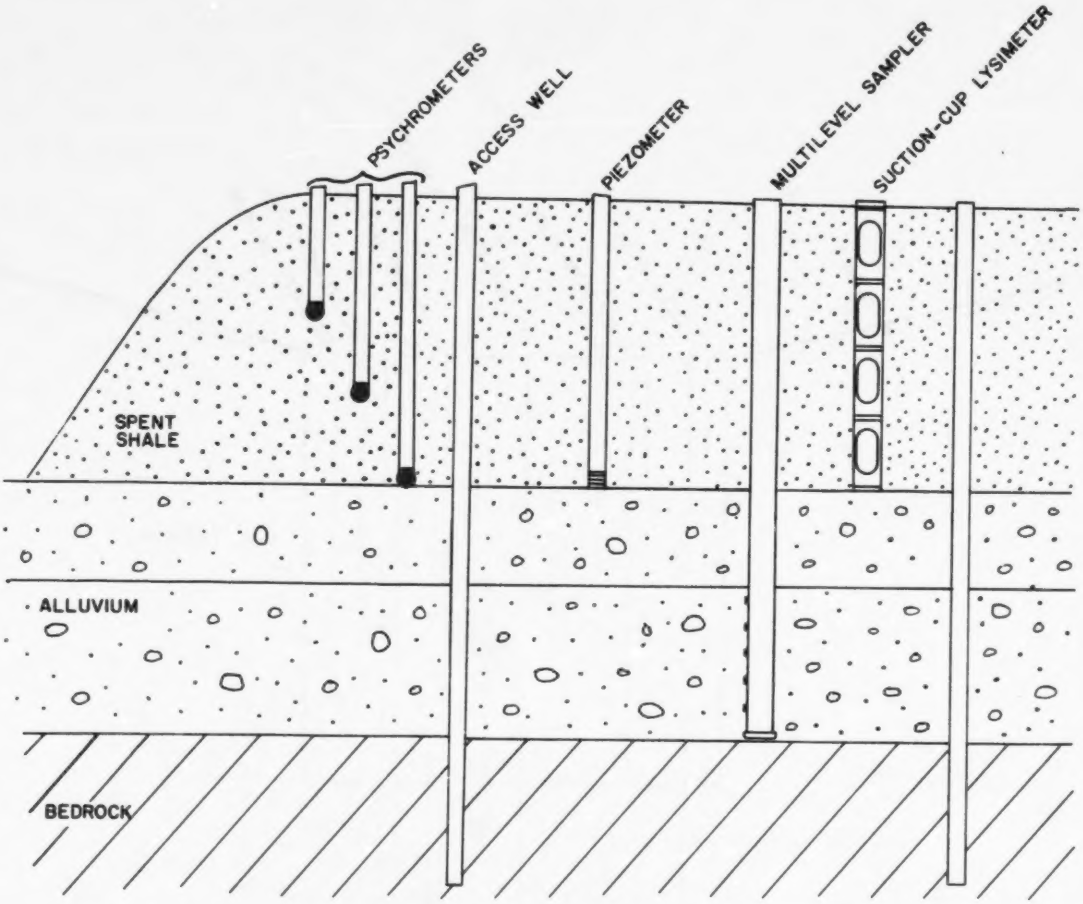


Figure 2-3. Possible monitoring facilities in the completed spent-shale pile.

vandalism. Figure 2-3 shows a possible collection of monitoring units in the completed pile.

Plans by the White River Shale Project indicate that, as the spent-shale pile advances into Southam Canyon, completed sections will be graded and prepared for revegetation. Trenches will be constructed and backfilled with soil. The objective of a revegetation program is to promote lateral growth of vegetation away from the trenches. Because of the high salinity in spent shale, it may be necessary to leach salts from the root zones prior to initiating a revegetation program. Access wells, moisture blocks, salinity sensors, psychrometers, and tensiometers should also be installed within and below the soils of the revegetation trenches at representative sites (Figure 2-4). The access wells should extend well below the revegetation trenches, into the underlying spent shale, to permit observing water-content changes during irrigation of the trenches, water harvesting, and high-intensity precipitation events. In addition, suction-cup lysimeters can be positioned at

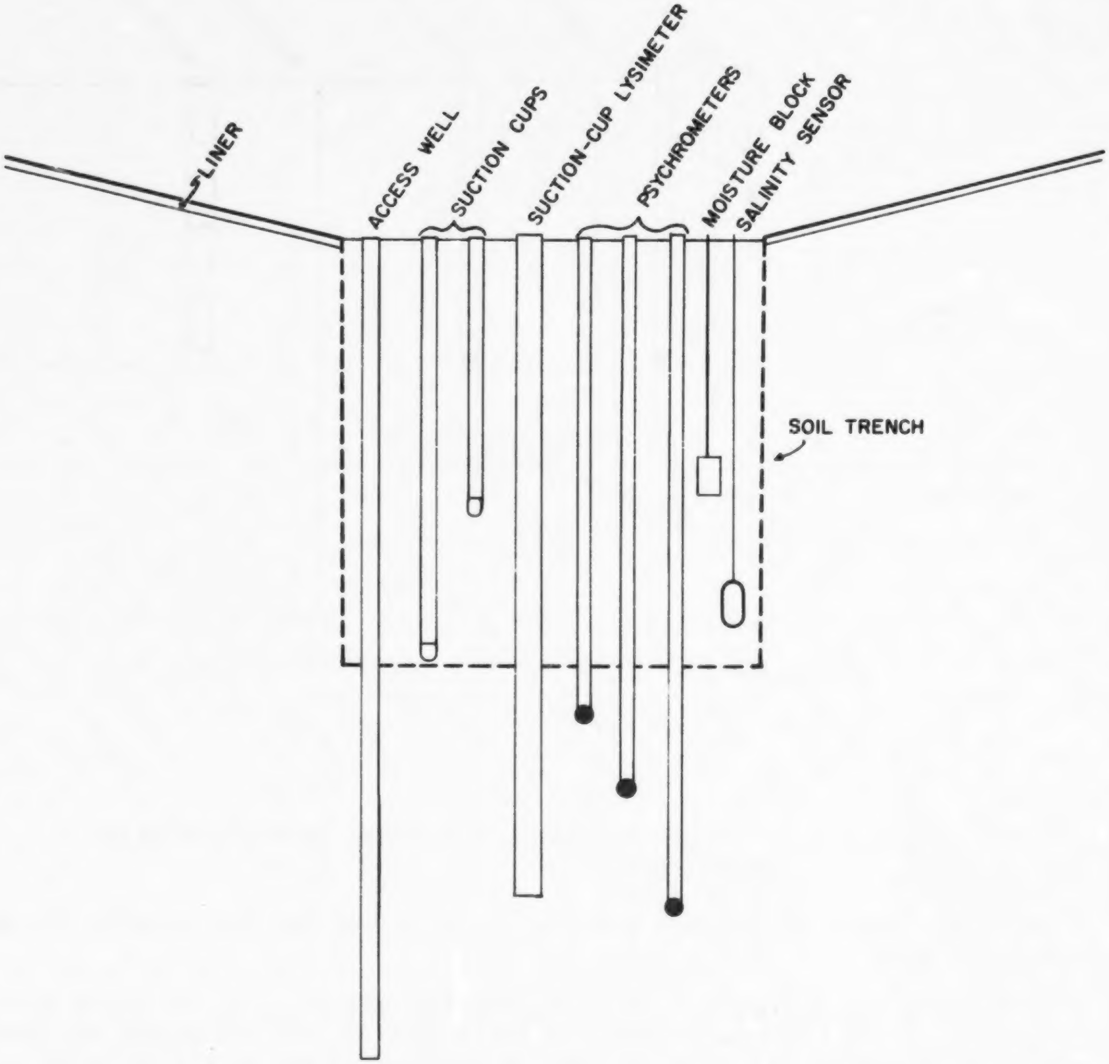

LINER
ACCESS WELL
SUCTION CUPS
SUCTION-CUP LYSIMETER
PSYCHROMETERS
MOISTURE BLOCK
SALINITY SENSOR
SOIL TRENCH

Figure 2-4. Possible monitoring facilities in soil trenches. The spatial distribution of sensor sites would be wider than depicted in this schematic.

three or four locations down to about 50 feet to permit sampling of downward-flowing leachate (Figure 2-5). Thermocouple psychrometers should be located near the suction-cup lysimeters to measure the pore water pressure for operating the suction-cup units.

Along with monitoring at the revegetation trenches, an intensive sampling program may also be initiated in the vicinity of the toe of the completed spent-shale pile. Lower reaches of the pile may become saturated as a result of leaching for salinity control or because of subsurface movement of water from trenches. Leachate produced by saturated conditions may flow out of the pile into downstream alluvium or downward into the Uinta Formation.

A schematic representation of the toe of the pile and possible monitoring units is shown in Figure 2-6. This schematic shows several access wells installed from the surface to the base of the pile. These wells may be logged to determine the presence of a free surface. One access well is shown extending downward to the Uinta Formation. If saturation is detected in basal regions of the pile and underlying alluvium, small-diameter wells (piezometers) with screened well points would then be installed at staggered intervals. In addition to the small-diameter wells, a multilevel sampling well may be constructed within alluvial water-bearing material near the toe of the pile. Sampling these wells would identify vertical gradations in quality of leachate beneath the water table.

Suction-cup lysimeters can also be used to sample leachate flowing in unsaturated and saturated regions of the toe. Locations and numbers of these units should be based on results of moisture logging in access wells. Psychrometers or tensiometers can be used to determine the vacuum to apply to the suction cups.

A further check on possible infiltration can be accomplished by the examination of outcrops of claystone partings below the shale pile for signs of undue seepage. If infiltration does occur through the shale pile and is not detected in the monitoring wells, the water will very likely discharge somewhere downgradient.

Initial monitoring can be used to design subsequent monitoring sites for the processed-shale disposal pile. Neutron moisture-logging wells can be installed to locate possible water-conducting zones (Figure 2-7). If such zones are detected, a sampling well equipped with suction-cup lysimeters or other sensors can then be installed at several depths in the sampling well. One method for installing suction cups is to grout or otherwise seal off a region of the well near a water-conducting zone, emplace a suction-cup lysimeter, backfill with sand, and seal off the top of the sampling region. In this manner, three or four suction cups can be installed in each well. As previously described, access wells can also be perforated and used to collect water samples.

As another method of sampling within the disposal piles prior to construction of landfills, manifold collectors can be placed in trenches slightly below the ground level at several locations (Figure 2-8). Such collectors

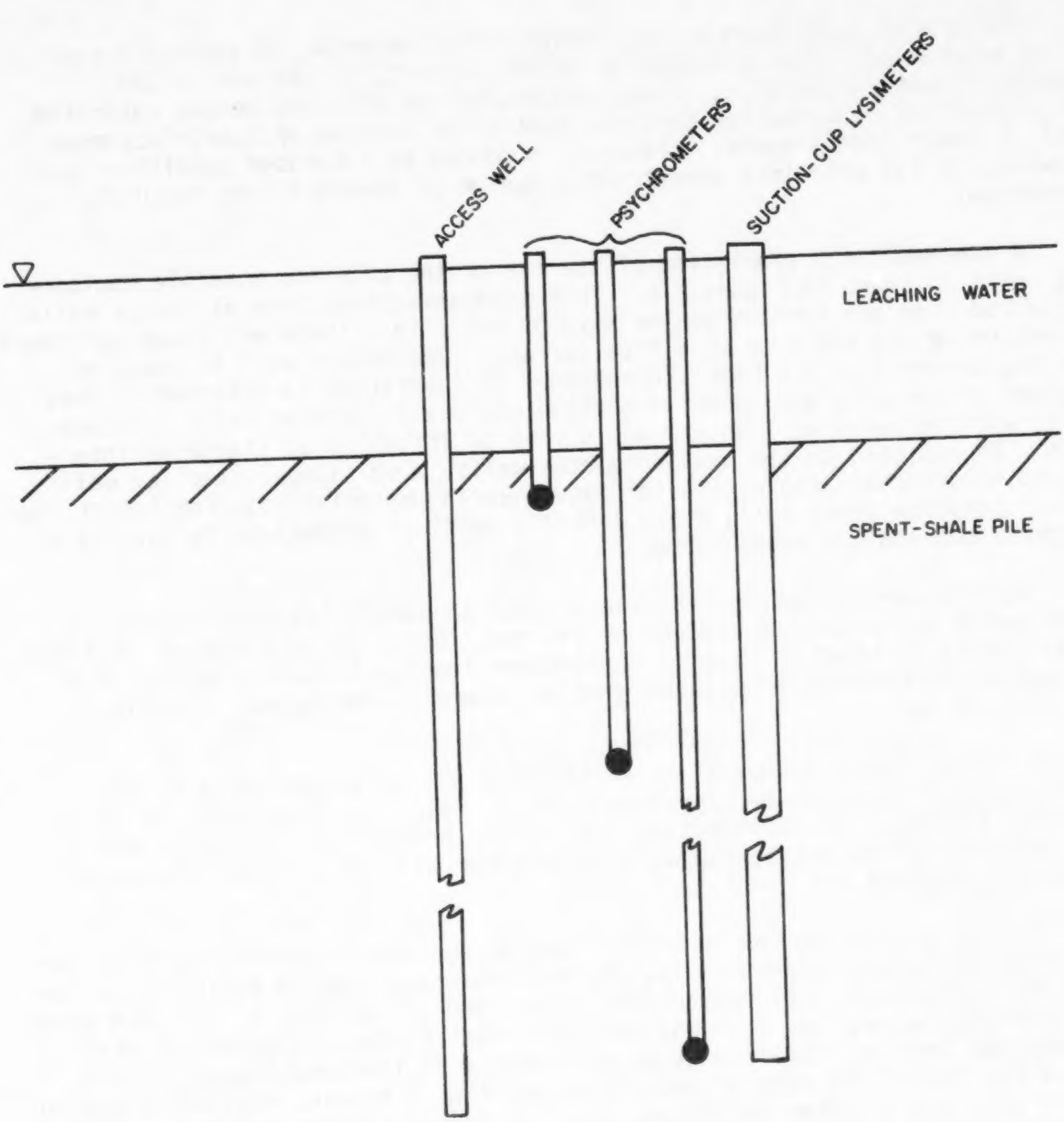

ACCESS WELL
PSYCHROMETERS
SUCTION-CUP LYSIMETERS
LEACHING WATER
SPENT-SHALE PILE

Figure 2-5. Possible monitoring facilities during leaching of spent-shale pile for salinity control.

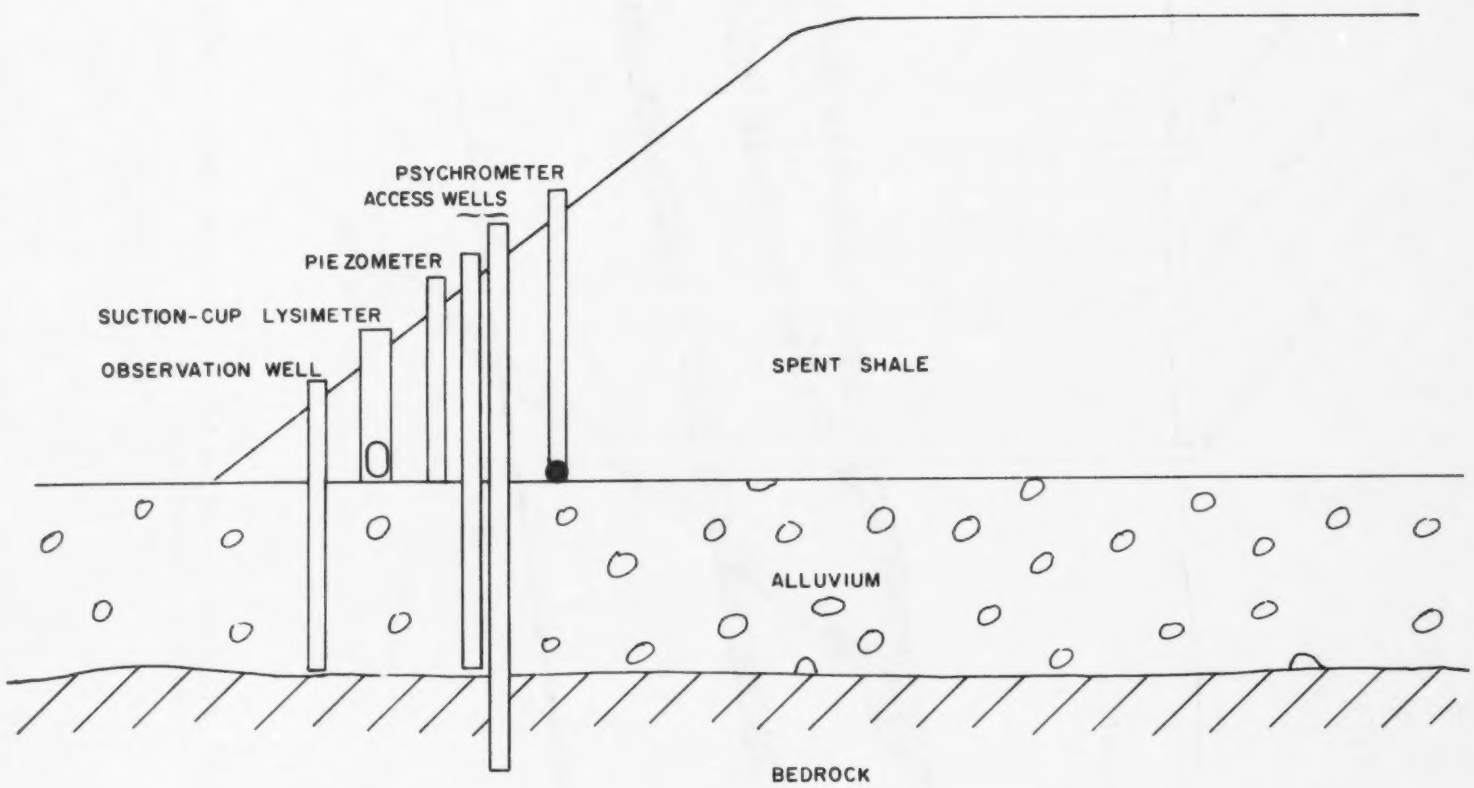

PSYCHROMETER
ACCESS WELLS
PIEZOMETER
SUCTION-CUP LYSIMETER
OBSERVATION WELL
SPENT SHALE
ALLUVIUM
BEDROCK

Figure 2-6. Possible monitoring facilities in the toe of the spent-shale pile.

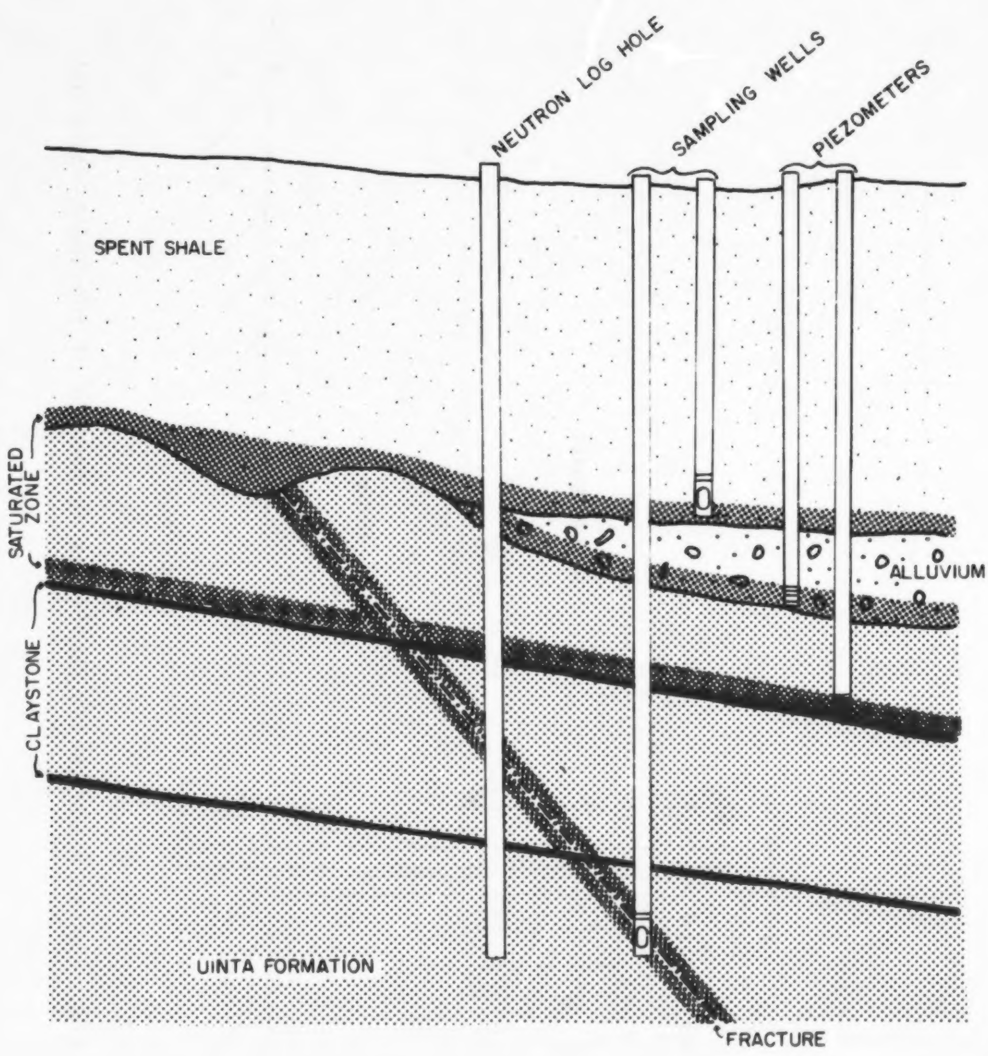

NEUTRON LOG HOLE
SAMPLING WELLS
PIEZOMETERS
SPENT SHALE
SATURATED ZONE
ALLUVIUM
CLAYSTONE
UINTA FORMATION
FRACTURE

Figure 2-7. Proposed monitoring faciities in the spent-shale pile and Uinta Formation.

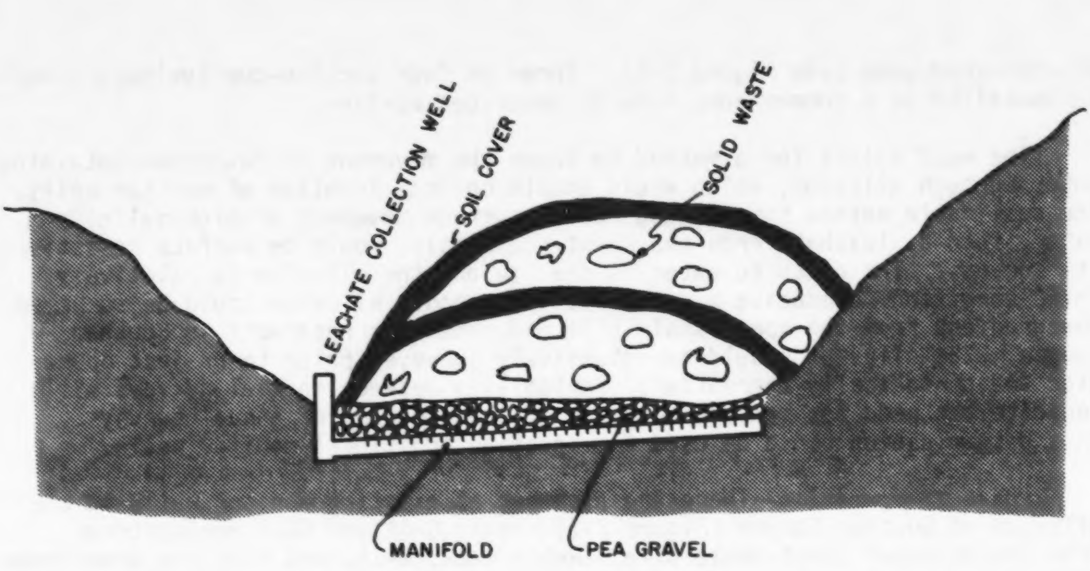


Figure 2-8. Sanitary landfill with PVC collector manifold.

containing slits or openings to permit inflow of water or leachate are covered with clean pea gravel during installation. The manifold tubing is installed at a slight slope to permit drainage into a sump with an upright collector pipe. This pipe can be located far enough from construction activities to avoid damage. Later, as the spent shale envelops each landfill, joints would be added to the collector pipe to ensure surface access. This "horizontal collector" scheme would avoid many of the problems associated with heavy equipment work and vertical wells extending through the surface of the pile. However, a manifold will operate only under saturated flow conditions and should be underlain by an impervious layer or membrane.

Alluvium--Proposed White River Shale Project monitoring programs include installation of shallow alluvial observation wells near the foot of the processed-shale pile. Results from such a program would also provide information on leachate contamination of the shallow water table (if present). As the pile advances, the test wells are to be abandoned and new wells constructed downstream.

An alternative monitoring program would supplement these activities by installing additional alluvial monitor wells at sites determined by thorough studies on alluvium in Southam Canyon (see hydrogeologic framework studies outlined earlier in this section). Wells can be installed upstream and downstream of proposed landfill locations and within alluvium underlying the sites. Installation of multilevel sampling wells can provide data on vertical gradations in quality (Figure 2-2). Alternately, clusters of piezometers can be installed to permit vertical sampling.

Depending on the results of preliminary studies on water movement beneath proposed landfill sites and assuming that soils and alluvium are to be left in place, suction cups may be installed in underlying soils, alluvium, or weathered zone (see Figure 2-9). Three or four suction-cup lysimeters may be installed in a common bore hole as described earlier.

The need exists for a method to trace the movement of leachate-containing water through alluvium, which would enable optimal location of monitor wells. One applicable method for tracing the subsurface movement of high-salinity water, such as leachate from the spent-shale pile, would be surface resistivity surveys. The depth to water is shallow and the alluvium is relatively thin, conditions conducive to use of this method. Alluvium could be surveyed downgradient from the spent-shale pile and retention reservoir in Southam Canyon. The alluvium should be intensively surveyed prior to project operation and periodically thereafter. Variability between initial surveys will indicate the need for seasonal surveys or the adequacy of annual surveys. This determination could be used for locating additional monitor wells.

Phase II operation--There are a number of existing monitor wells in the alluvium of Southam Canyon (Figure 2-1). Wells G-4A and AG-7 are upstream from the proposed spent-shale pile. Wells G-2A, G-1A, and AG-6 are downstream of the spent-shale pile, and well AG-3 is along a tributary to the main drainage in Southam Canyon. A number of additional alluvial monitor wells are planned by the White River Shale Project near the proposed retention reservoir. Additional monitor wells are needed along the main drainage just upstream from the proposed reservoir and spent-shale pile. However, it is unknown if a sufficient thickness of saturated alluvium is present in the latter areas. This can be determined by test drilling or possibly by geophysical surveys.

Alternatives include placing wells downstream from the retention reservoir, upstream of the reservoir, and along smaller drainages upstream from the proposed spent-shale pile.

A typical monitor well would be a relatively large-diameter (e.g., up to 12 inches) hole drilled to the base of the alluvium. Somewhat smaller diameter (e.g., 6-inch) PVC casing would be installed to the bottom of the hole. However, since data on aquifer characteristics of the alluvium are sparse, several larger wells (equipped, perhaps, with casing up to 8 inches in diameter) may be needed. This would require a 14-inch-diameter hole. However, the low capacity of wells in this alluvial system may make smaller wells acceptable for use in these assessments. The casing should be perforated opposite the interval from below the static water level to the bottom. Clean pea gravel of known inert composition should be used to pack the well. The upper several feet should be filled with cement to form an annular seal. The wells should be logged by a geologist during drilling and developed by using an airlift or pump upon completion. A locking cap should be installed along with a suitable barrier to prevent destruction. Where bailing or or other nonpumping methods are employed, smaller diameter wells can be installed.

Water samples may best be obtained by installation of suitable submersible pumps for the reasons discussed in the segment of this section addressing monitoring deficiencies of the program proposed by the White River Shale Project. However, it should be noted that well yields may be too low to use pumping. Assuming pumping is utilized, a submersible pump should be installed

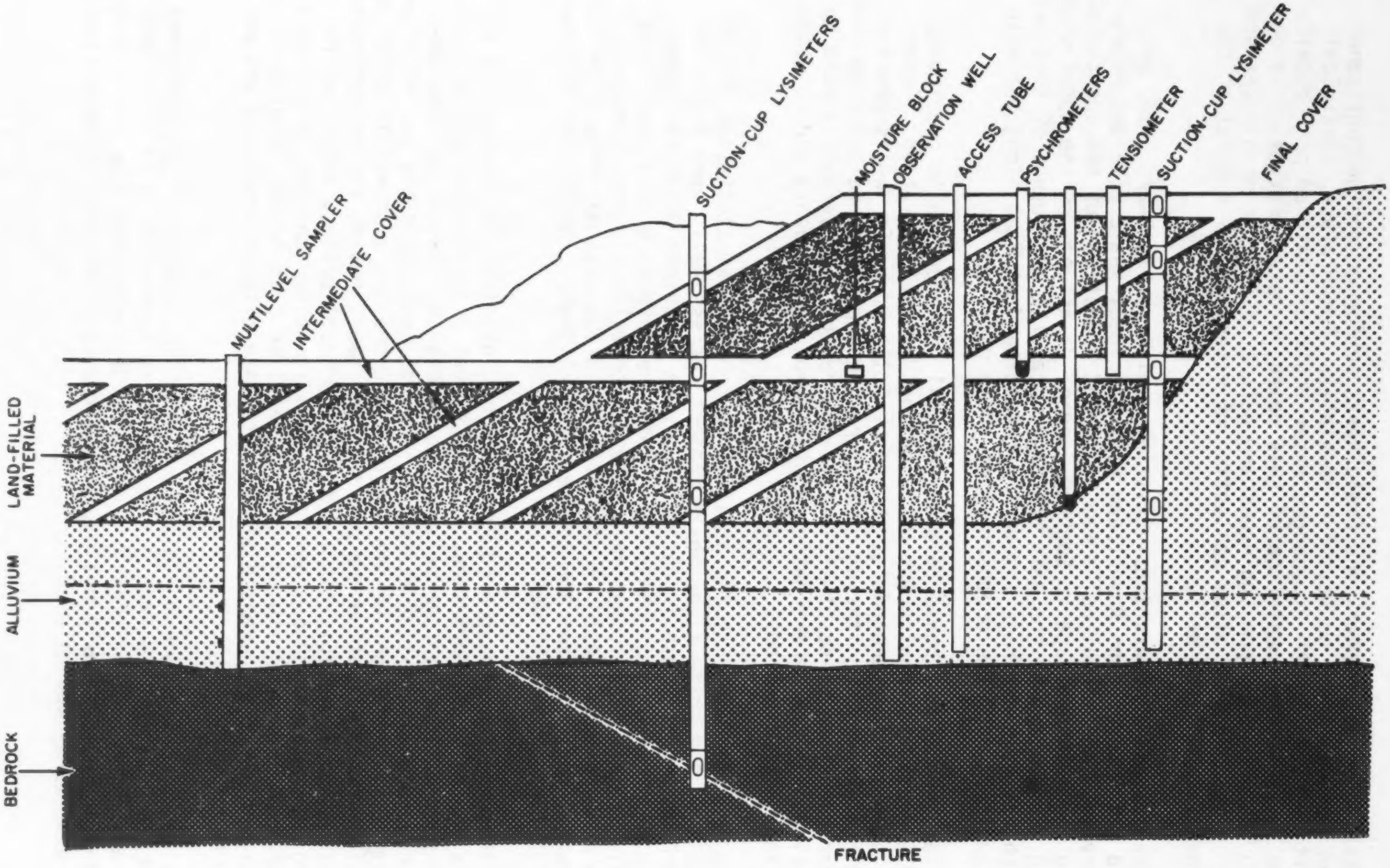

MULTILEVEL SAMPLER
INTERMEDIATE COVER
SUCTION-CUP LYSIMETERS
MOISTURE BLOCK
OBSERVATION WELL
ACCESS TUBE
PSYCHROMETERS
TENSIOMETER
SUCTION-CUP LYSIMETER
FINAL COVER
LAND-FILLED MATERIAL
ALLUVIUM
BEDROCK
FRACTURE

Figure 2-9. Possible monitoring facilities in the landfill.

upon completion of development and field tests performed during continuous pumping for several hours or days (if possible). Temperature, electrical conductivity, and pH of the discharged water could be measured periodically during the test. After completion of this phase, a determination could be made as to the period of pumping necessary before collection of a water sample. This procedure will allow collection of water samples typical of the alluvium near the monitor well.

Phases III and IV operations--Existing monitor wells G-2A, G-1A, and AG-6 would still be present downstream from the spent-shale pile and retention reservoir. Additional wells may be needed downstream of the spent-shale pile along the main drainage in Southam Canyon, downstream of the spent-shale pile along a tributary to the main drainage, near the confluence of this tributary with the main drainage (above the retention dam), and along the main drainage upstream from the proposed spent-shale pile.

The same procedure should be used for well construction as previously discussed for alluvial monitoring wells during Phase II operation. Generally, the same sampling procedures should be followed as for wells previously presented for alluvium monitoring. However, the experience gained from monitoring near the Phase II spent-shale pile and retention reservoir should be used, particularly for determination of the sampling frequency and selection of analytical determinations.

Uinta Formation--During the initial hydrogeological studies on the oil shale tracts by the White River Shale Project, access wells were installed in the Uinta Formation for use in conjunction with a neutron moisture logger. Wells were grout encased. Inconclusive moisture data were obtained (White River Shale Project, 1976), possibly because the wells did not intersect fractures or bedding planes. In addition, the grout seal may have moderated the epithermal neutrons from the source, or infiltration quantities may have been insignificant near the wells.

Suitable construction procedures should be utilized for installing access wells in the Uinta Formation. To the extent possible, methods will be used to ensure a tight contact between the access-well casing and the sandstone (i.e., to minimize side leakage). Several test wells may be installed at representative locations within bedrock outcrops and also within alluvium. For the study of infiltration and percolation, small basins can be sprinkled to simulate natural precipitation. After water application, access wells can then be logged using neutron probe techniques to follow changes in moisture with depth and time. Particular attention will be paid to the development of perched groundwater, for example at the interface between weathered and unweathered materials.

Suction-cup lysimeters may also be useful for sampling fractured zones up to a depth of about 125 feet. An alternative technique is to drill angle wells in areas found to be highly fractured. The wells would be perforated in regular intervals. For sampling, a packer pump, such as the Casee Sample (Fenn et al., 1975) can be used.

Green River Formation--The DDP indicates that groundwater samples will be obtained in wells upstream of the spent-shale disposal area (wells P-3, G-11) and in downstream wells (wells P-2, G-2A, G-21). Ostensibly, samples from these wells would also be used to detect the presence of both spent-shale and landfill leachate. In addition to sampling of deep aquifers, wells constructed near the White River in the Green River Formation above the Bird's Nest Aquifer during characterization of the hydrogeologic framework should be included for monitoring pollutant mobility.

Phase II operation--Despite the presence of an apparent confining bed above the Bird's Nest Aquifer, sampling may be needed to allow direct determination of groundwater pollution. There are two existing wells (P-3 and G-7) about 1 mile from the proposed spent-shale pile (Figure 2-1). Well G-15 is about 1/2 mile from (and is neither upgradient nor downgradient from) the proposed spent-shale pile. Wells G-5 and G-21 are within 1 mile of the proposed reservoir and pile, but are not upgradient or downgradient. Any number of wells are possible, depending on economic considerations and other factors. Options include additional wells upgradient of the spent-shale pile, downgradient of the spent-shale pile, and downgradient of the retention reservoir. Since additional data are necessary on hydraulic characteristics of the Bird's Nest Aquifer, all of these wells should be constructed so as to permit aquifer testing.

The monitor wells would comprise a large-diameter (e.g., 14-inch) hole drilled to the base of the Bird's Nest Aquifer. A smaller diameter (e.g., 8-inch) PVC casing would be installed to the bottom of the hole and should be perforated opposite the Bird's Nest Aquifer. Because of the great depths of the Bird's Nest Aquifer (and Douglas Creek Aquifer), steel casing may be necessary. Clean pea gravel of known composition should be used to pack the hole. The upper 20 feet should be filled with cement to form an annular seal. The wells should be logged by a geologist during drilling and the well developed using an air lift or pump upon completion. A locking cap and barrier should be installed.

Despite the relatively great depth of the Douglas Creek Aquifer, sampling is necessary because Douglas Creek is potentially a major aquifer and because hydraulic head relations between the Bird's Nest Aquifer and groundwater in the Douglas Creek Aquifer are poorly known at present.

There are no wells effectively penetrating the Douglas Creek Aquifer within 3 miles of the proposed shale pile. For monitoring purposes, additional wells may be placed upgradient of the proposed spent-shale pile, downgradient of the shale pile, and downgradient of the retention reservoir. Similar construction techniques should be followed as for the new monitor wells in the Bird's Nest Aquifer. However, in this case, the casing should be perforated opposite the Douglas Creek Aquifer. The well should be gravel packed opposite this interval and bentonite or cement added opposite the Bird's Nest Aquifer so that interaquifer flow does not occur.

Phases III and IV operation--Existing wells G-15 and G-21, and possibly other additional monitoring wells that may be constructed in the Bird's Nest Aquifer or Douglas Creek Aquifer, are in the area to be covered with spent shale in Phases III and IV. These wells can be preserved by extending the casing upward as the spent shale is placed. However, extreme care must be taken to prevent damage to the casing.

Existing wells P-3 and G-7 are upgradient and P-2 is downgradient of the proposed pile. Considering the large size of the spent-shale pile, a number of new wells in the Bird's Nest and Douglas Creek Aquifers may be necessary along the periphery of the spent-shale pile. Construction procedures similar to those previously discussed should be used.

The same monitoring procedures presented previously for Phase II are applicable here. However, the experience gained from monitoring the Phase II spent-shale pile should be used, particularly for determination of sampling frequency and selection of analytical determinations.

Sampling Frequency--

Requirements for sampling frequency in the processed-shale pile are dependent upon several factors, including observation of runoff or seepage, observed changes in moisture content within disposal piles or landfills, and phase of operation (e.g., pile construction, leaching of surface layers for salinity control, surface sealing (water harvesting), and breakdown of surface seal). Location will also influence sampling-frequency needs. For example, downstream alluvial wells should probably be sampled on a frequency depending on closeness to the waste-disposal pile, with those near or within the pile being sampled most frequently.

During construction of disposal piles, samples of runoff can be collected in and around the disposal area. Similarly, seepage flows from the pile should be sampled as observed. Such observations are expected to be seasonal and infrequent. If flows continue for extended periods (several days), collection of daily samples may be indicated.

Sampling in unsaturated zones will be closely associated with monitoring of moisture content. In other words, sampling frequency will be governed by availability of water. Samples should be collected wherever water is available. Collection of samples from suction cups is a function of pore water pressure (or the rate at which water enters the porous cup). At pressures less than -0.8 atmosphere, samples cannot be obtained.

From the preceding discussion, it does not seem appropriate at this time to define a detailed sampling schedule for pollutant mobility monitoring in the processed-shale disposal area. Frequencies would be best defined after field monitoring of moisture content and of subsurface water movement has been initiated, and as a response to those observations. Initial assessment of potential rates of mobility would allow definition of basic sampling frequencies for pollutant mobility monitoring. These frequencies may designate the final sampling program; alternatively, the program could be designed for variable frequency sampling, depending on the nature of observed results.

Determination of well-sampling frequency is dependent upon the results of the pumping-versus-bailing evaluations discussed earlier. If it is concluded that bailing has not biased the results obtained during the baseline period, then frequencies such as proposed by the tract developers (quarterly for alluvial systems and semiannually for the deeper aquifers) may be appropriate. If bailing is not an adequate sampling procedure, then an appropriate frequency will have to be developed.

Options for sampling frequency thus include:

- Sampling at all sites on a basic schedule (e.g., quarterly)
- Sampling certain sites (e.g., sites nearer the disposal pile) at a frequency greater than that used at other sites
- Sampling only in response to indicated changes in water content in the unsaturated zone
- Sampling only runoff or seepage when visually detected
- Sampling at more frequent intervals if water quality changes warrant.

Certain combinations of these options may also be appropriate. Alternatives also exist with regard to the frequency at which a given chemical constituent analysis is performed on water samples collected. This is discussed further in the following paragraphs.

Analytical Methods--

Analysis programs--Alternative analytical procedures, discussed earlier with regard to characterizing potential pollution sources, are also appropriate for the monitoring of pollutant mobility. Constituents considered for monitoring have been categorized as general measures of water quality (e.g., pH or TDS), major inorganic constituents (e.g., Na, Cl, or SO_4), selected trace elements (e.g., As or Se), organics (e.g., DOC, COD, or specific organic compounds), radiological constituents, and bacteriological parameters. Alternatives for analysis can be outlined as follows:

- Alternative category or categories to be analyzed
  - General water quality measures
  - Major inorganic constituents
  - Trace elements
  - Organics--general measures (e.g., DOC)
  - Organics--more specific measures (e.g., organic fractionation, phenolic compounds, etc.)
  - Radiological parameters

  - Bacteriological parameters
  - Various combinations of the above categories

- Alternative sampling and analysis sequences
  - "Basic program" of general water quality measures followed by more detailed analysis if changes are noted
  - "Basic program" at some defined frequency with more detailed analyses at less frequent but defined frequency
  - Analyses for both general and individual constituents at some defined frequency
  - Some combination of the above sequences.

Quality control and quality assurance--Quality control procedures are implemented as part of a monitoring program to insure the reliability of the data collected. Because monitoring data are used as the basis for various decisions (e.g., determining compliance with regulations or need to implement environmental control measures), quality control procedures for both field and laboratory segments of the monitoring programs are essential. In addition, quality assurance proceedings are implemented to provide documentation of the quality control efforts.

Quality control activities included as part of the field monitoring and sample collection include the following:

- Instrument calibration (e.g., use of proper standards, proper number of standards, and appropriate frequency of recalibration)
- Use of appropriate sample handling procedures
  - Appropriate bottle type (e.g., clear glass, dark glass, sterile bottles, PVC)
  - Measurement of conductivity, pH, etc. during pumping of wells for sampling to obtain representative samples
  - Proper field processing and preservation (e.g., filtration, addition of chemical preservatives, and cooling)
  - Proper packing and shipment to analytical laboratory
- Proper training of personnel involved in field activities, including actual data collection activities as well as quality control and quality assurance procedures.

Quality control procedures are also required in the analytical laboratory. Procedures include:

- Use of standard, accepted analytical methods
- Use of analytical grade reagents, good pure-water source, etc.
- Instrument calibration
- Use of standard reference samples
- Use of spiked samples
- Duplication of analysis
- Training of personnel.

Details of laboratory quality control procedures are presented by the Analytical Quality Control Laboratory (U.S. Environmental Protection Agency, 1972). Predefined standards of performance are an essential component of these programs.

The U.S. Environmental Protection Agency (EPA) has established a program to audit analytic laboratories. Audits include analysis of standard samples and laboratory inspection by EPA personnel to evaluate analytical methodology, data validity, and various aspects of the laboratory quality control program. Although they do not constitute a certification, such audits can be useful for evaluating and selecting a laboratory for chemical analysis. Quality control programs for monitoring programs may include periodic repetitions of independent audits, such as that conducted by the EPA, analysis of blind (i.e., not identified to the laboratory) duplicates, and analysis of blind standard samples (such as can be supplied by EPA). Such procedures should be implemented as part of the overall monitoring program design.

Data analysis--Data analysis procedures include checks on data validity and methods for presenting data for interpretation for environmental description or control purposes. Data checking procedures include:

- Cation-anion balance
- TDS-conductivity comparison
- Conductivity-ion (milliequivalent/liter) comparison
- Diluted-conductance method.

The cation-anion balance check involves considering the theoretical equivalence of the sum of the cations (expressed in milliequivalents per liter) and the sum of the anions. Because of variations in analysis that may be unavoidable, exact equivalence is seldom achieved. In general, the observed inequality can be expected to increase as the total ionic concentration increases. When using this method, it is assumed that analysis of all significant ions have been included and that the nature of the ionic species is known. In addition, it should be noted that compensating analytical errors can fortuitously produce a close ion balance. Hence, a combination of quality control and data-checking procedures should be employed.

Given the above listed assumptions, the cation and anion concentrations should be relatively close. Brown et al. (1970) indicate that the deviation between the cations and anions should not exceed 1 or 2 percent of the total concentration for analyses of waters with more than 150 milligrams per liter dissolved solids. American Public Health Association (1976) shows a control chart indicating acceptable limits of ±1 standard deviation. This "standard deviation" is not defined, but the illustration indicates acceptable limits equivalent to about 2 percent difference in total cations and total anions, relative to the sum of the anions.

The acceptance limits for analytical accuracy used by the U.S. Environmental Protection Agency in laboratory audits with standard samples as described above are also ±1 standard deviation (the 68 percent confidence level). This standard deviation for individual analyses is computed from results obtained by submitting samples to a number of State, Federal, and private laboratories and is typically on the order of 5 to 12 percent. Using ±1 standard deviation as an acceptance limit for the cation-anion balance would result in limits also in the 5 to 12 percent range (relative to the total ionic concentration).

The U.S. Geological Survey has indicated ion differences typically in the range of ±7 percent at the 84 percent confidence interval (somewhat greater than ±1 standard deviation) on waters of high salt content (John Wallace, Denver Research Institute, personal communication). The USGS ion balance calculations include results of analysis of about 18 constituents.

For other analysis checks, samples can be evaporated to dryness at 180°C and the weight compared to the total solids determined by calculation. This check is approximate because losses may occur during drying by volatilization and other factors may cause interference (Brown et al., 1970). Another recommended check on analyses involves multiplying specific conductance (micromhos per centimeter) by a factor ranging from 0.55 to 0.75. The product should approximately equal total dissolved solids in milligrams per liter, for water samples with TDS below 2,000 to 3,000 milligrams per liter. Also, the specific conductance divided by 100 should approximately equal the milliequivalents per liter of anions or cations. This relationship is useful in deciding on which sum, cations or anions, is in error. A more refined method for checking TDS by the EC relationships, called the diluted-conductance method, is given by American Public Health Association (1976) and by Brown et al. (1970).

Data presentation--Data presentation and interpretation are key aspects of monitoring for environmental detection and control. Needs for data interpretation have been discussed earlier. Several methods are available for organization and presentation of chemical data. These include:

- Tabulation (e.g., with accompanying tabulation of appropriate water quality criteria or standards)

- Graphical presentation
  - -- Time-series plots (perhaps with accompanying plot of water quality criteria)
  - -- Control charts (similar to time-series)
  - -- Trilinear diagrams
  - -- Stiff diagrams
  - -- Histograms, circular diagrams, etc.
  - -- Contour maps
- Statistical or computer measures (e.g., water quality indices).

Data handling and processing capabilities are another important aspect of monitoring. Data that can be easily and rapidly accessed are clearly advantageous for interpreting and planning purposes.

MONITORING PROGRAM DEVELOPMENT

In the following discussion, a plan for development of a recommended groundwater quality monitoring program is presented.

Pollutant-Source Characterization

Details of Disposal and Revegetation Operation--

During the development and operation of the oil shale facilities, onsite inspection of disposal procedures is recommended on a regular basis. Observations should include the following:

- Preparation of Southam Canyon before disposal (removal of soils down to the Uinta Formation, storage of removed materials, etc.)
- Procedures for transport, spreading, contouring, and compaction of processed shale
- Placement of other solid and liquid wastes in or on the processed-shale pile
- Surface sealing of processed-shale pile
- Construction of revegetation trenches
- Irrigation or imposed-leaching activities.

Observations should be documented in writing and by photographs. The documentation should be transmitted to the designated monitoring agency (DMA), tract developers, and USGS for comment and discussion.

The frequency of these onsite surveys will vary according to the intensity of activities. For example, during project initiation (start of Phase II and start of Phases III and IV) weekly or biweekly tours should be made. As operations reach a steady state (during each development phase), survey frequency can be extended to perhaps monthly or even quarterly. As revegetation activities are initiated, more frequent (again perhaps weekly) observation would be required. The conduct of these surveys should be closely coordinated with pollutant mobility monitoring activities (e.g., instrument installation and sampling).

Waste Characterization--

Waste characterization activities include analyses of water-solid-waste interactions, solid-waste physical and chemical properties, and liquid-waste physical and chemical properties. These analysis categories are listed here in order of monitoring priority (Table 2-3).

Water-solid-waste interactions in the processed-shale disposal area may be addressed directly during infiltration and pollutant mobility monitoring evaluations. These are presented in detail in a later discussion and are not repeated here. At this time, predictive capabilities do not exist for the extrapolation of laboratory (e.g., development of soil-moisture characteristic curves or column or beaker tests for examination of sorption and leachate formation) or small-scale field test (e.g., lysimeter) results to a large-scale disposal problem such as found in the processed-shale disposal area. Development of this capability would greatly enhance the design of future oil shale monitoring activities. However, this research activity is considered to be beyond the scope of the monitoring development program discussed herein.

For the monitoring program, it is important to know the chemical characteristics of liquid wastes and of the soluble components of solid wastes. Development of the monitoring program should include analysis of liquid wastes and solid-waste-saturated extracts for the same chemical characteristics that will be presented later in discussions of pollutant mobility. Waste products to be included are (in decreasing order of priority):

1. Processed shale (saturated extract)
2. High-TDS waste water
3. Sour water
4. Spent catalysts (saturated extract)
5. Water treatment plant sludges (saturated extract)
6. Sulfur byproducts (saturated extract)
7. Oil waste waters
8. Spent filters (saturated extract)

9. Mine water.

Sampling frequency will be established during Phase II operation and will be reevaluated at the start of Phases III and IV operation. Initially, samples will be collected weekly for analysis. After 6 months (or approximately 25 samples), the variability between sampling periods will be evaluated and a frequency (such as quarterly) selected.

Water Use

Contact with the various agencies in Utah concerned with water resources and economic development yielded the following information:

1. Although no computer files or regular publications on water appropriation or water use exist, all new water appropriations are published for three consecutive weeks in the Vernal, Utah, newspaper. This information is published under the heading of "Notice for Water Users."
2. Water-use data (well permits, appropriations, etc.) are also on file (noncomputerized) with Utah Water Rights Division in Vernal.
3. The Utah Oil, Gas, and Mining Division issues monthly and yearly reports on these types of development activities. These publications are free.
4. The Utah Water Quality Bureau analyzes and evaluates water quality for all new domestic and public water supplies. These data are published in yearly report.
5. The Utah Industrial Development Division publishes "The Prospector" (free), which lists all industrial development activities in Utah.

Suggested water-use surveys of the project region include the following activities:

- Subscription and review of "Notice for Water Users" in the Vernal newspaper, Oil, Gas, and Mining Division reports, Water Quality Bureau publication of analyses, and "The Prospector"
- Annual review of these data with tract developers, the Utah Water Rights Division, Utah Bureau of Water Quality, and USGS.

Hydrogeologic Framework and Existing Water Quality

The three major monitoring deficiencies identified under this category are characterization of the alluvial system, fracturing in the Uinta Formation, and testing and sampling of the aquifers in the Green River Formation (Table 2-3). These items are listed here in descending order of priority for monitoring program development. Recommended approaches for monitoring program development are presented in the following paragraphs.

Characterization of Alluvium--

Recommended activities for monitoring program development are as follows:

- Geophysical surveys supplemented by test drilling to define the boundary condition for the alluvial system (i.e., thickness, subsurface extent, location of saturated zones)
- Aquifer testing of saturated zones identified
- Sampling of water quality of alluvial aquifer.

The purpose of these efforts would be to define the occurrence and movement of water in the alluvium.

Uinta and Green River Formations--

Fracturing in the Uinta Formation may create pathways for the mobility of pollutants from the processed-shale disposal area to the White River or to deep aquifers in the project region. Identification of the density and character of this fracturing is thus the key to evaluating pollutant mobility and development of the monitoring program.

As the materials in the alluvial channels and canyon slopes are cleared for construction of the processed-shale pile, visual surveys should be made of the surface of the Uinta Formation. Fracturing should be mapped and used for locating monitor sites for following mobility in the processed-shale disposal area. Test holes should be drilled into the Uinta Formation and the Green River Formation above the Bird's Nest Aquifer near the mouth of Southam Canyon. As saturated strata are identified, data on flow characteristics (gradients and tranmissivity) should be collected by installing and testing wells.

Deep Aquifers--

Testing recommended for the aquifers in the Green River Formation includes:

- Evaluation of water quality sampling procedures at existing and proposed wells to establish suitable sampling methods and sampling frequency
- Additional aquifer testing at existing wells
- Installation, aquifer testing, and water quality sampling on new wells in the Bird's Nest Aquifer and Douglas Creek Aquifer.

The new wells recommended are described in more detail in a later discussion of pollutant mobility monitoring. Construction of these new wells would provide more information on the subsurface geology, water levels, aquifer characteristics, and water quality in the Bird's Nest Aquifer and in the Douglas Creek Aquifer in the immediate vicinity of the processed-shale disposal area. The relationship of the Douglas Creek Aquifer to the Bird's Nest Aquifer would also be more clearly established.

Where casing size permits, aquifer testing in existing wells is also appropriate to better define aquifer characteristics in the project region. Water quality sample collection procedures could also be evaluated as an assessment of baseline water quality data and to determine sampling frequency requirements for monitoring.

Infiltration

Infiltration potential is to be evaluated to examine the water balance for the processed-shale pile and to provide a basis for monitoring pollutant mobility in the processed-shale disposal area. The two areas where infiltration is to be assessed are the surface of the disposal pile itself and the surface of the Uinta Formation (i.e., in fractures). For these assessments, it is recommended that double-ring infiltrometers be used as follows:

- At various stages of the construction of the processed-shale pile including:
  - As shale is spread before compaction
  - After compaction
  - After surface is sealed
  - During revegetation (i.e., in revegetation trenches)
- At the surface of cleared areas where the Uinta Formation is exposed.

In conjunction with these infiltration tests, monitoring of subsurface mobility should also be employed as presented in the following discussions. This program would then offer the opportunity for assessing infiltration, for estimating subsurface hydraulic conductivity, for testing various pieces of monitoring equipment (e.g., moisture blocks, suction-cup lysimeters, and neutron probes), and, via sample collection, for analyzing leachate formation and composition.

Pollutant Mobility

Pollutant mobility monitoring needs in the processed-shale disposal area include monitoring in the processed-shale pile itself, in the Southam Canyon alluvium, in the Uinta Formation, in the Green River Formation above the Bird's Nest Aquifer, and in deep aquifers (Bird's Nest Aquifer and Douglas Creek Aquifer). This listing is in diminishing order of priority for monitoring pollutant mobility. Specific recommendations are provided in the following paragraphs.

The general approach for pollutant mobility monitoring in the processed-shale disposal area is a sequence of sensing and response activities. There are significant uncertainties with regard to water movement (and hence solute mobility) within the processed-shale pile. Initial monitoring activities should address the potential for water movements through the use of infiltration testing and subsurface moisture sensing (within the spent-shale pile) during these tests and during natural precipitation events. If this monitoring indicates mobility within the pile, then more intense direct sampling of water within the pile, in the alluvium, and in the Uinta Formation may be indicated depending on the nature and extent of the indicated mobility. Finally, if appreciable pollutant mobility is sensed in the Uinta Formation or the Green River Formation above the Bird's Nest Aquifer, more extensive monitoring in the deep aquifers may be required.

Processed-Shale Pile--

The monitoring of the processed-shale disposal pile includes the sensing of changes in moisture content (thus potentially inferring movement of water and solute materials) and the collection and characterization of these solute materials. The development of the monitoring program should be initiated with the infiltration evaluations presented above. Infiltration test sites should be instrumented as follows:

- Water content (or soil water pressure) sensing:
  - -- Access well for neutron moisture logging
  - -- Soil moisture blocks (at various depths)
  - -- Salinity sensors
- Water quality should be sampled via suction-cup lysimeters (tensiometers should be used to appropriate suction levels).

The goal of these testing and monitoring efforts would be to address the following issues related to monitoring design:

1. Can neutron logging follow changes in moisture content in a processed-shale pile?
2. What is the response of moisture blocks, salinity sensors, and tensiometers to water movement in processed shale?
3. Can suction-cup lysimeters be used to collect water samples?
4. What is the quality of percolating waters?
5. What is the rate of potential pollutant mobility in the processed-shale pile?

These data would be used to verify preliminary assessments of groundwater quality impacts and to test procedures for monitoring.

As indicated above, a sequence of infiltration tests during the various stages of pile construction is recommended. The initial testing of spent shale before and after compaction forms the basis of initial monitoring of the disposal pile. The test sites should be maintained as long as possible during pile construction. As benches are formed in the disposal pile, permanent monitoring sites should then be established on the benches with access (neutron logging) tubes, tensiometers, or other sensors demonstrated to be applicable to infiltration testing. Tests conducted after pile construction (i.e., after surface sealing, and associated with revegetation efforts) will be used to "fine tune" monitoring efforts for these final modifications of the processed-shale pile.

Monitoring installations in completed segments of the processed-shale pile would include selected infiltration test sites as described above and selected sites associated with revegetation trenches such as depicted in Figure 2-4. These trench sites are appropriate because water-harvesting efforts make these the most likely initial locations of infiltrating water. Access tubes for neutron logging, tensiometers, suction-cup lysimeters, or other monitoring devices shown to be suitable during the infiltration testing would extend below the trenches into the processed-shale pile itself. Should appreciable pollutant flux be indicated by monitoring within the processed-shale pile, monitoring in the natural hydrogeologic realm would be indicated as described in the following paragraphs.

Alluvium--

Monitoring in the alluvium in the processed-shale disposal area is presented below. Phase II and Phases III and IV of tract operation are considered separately. This monitoring would support monitoring of proposed (White River Shale Project, 1976) temporary wells near the toe of the processed-shale pile. Monitoring of the alluvial unsaturated zone is considered in Section 4 along with the retention-dams evalution.

Phase II operation--The applicable indirect sampling approach for tracing the subsurface movement of high-salinity water, such as leachate from the spent-shale pile, would be surface resistivity surveys. The depth of water is shallow and the alluvium is relatively thin. Alluvium should be surveyed downgradient from the spent-shale pile and retention reservoir in Southam Canyon. There are a number of existing monitor wells in the alluvium of Southam Canyon. The alluvium should be surveyed at least twice prior to project operation and at least annually thereafter. The initial surveys should be conducted during wet and dry seasons. These data should be supplemented by measurement of water levels, pH, and conductivity of water in piezometers installed in test holes drilled during initial characterization of alluvium.

Should surface resistivity surveys or piezometer sampling result in positive indications of leachate formation, additional samples from the piezometers for more complete analysis would be collected. The survey results would also be used to locate monitor wells to sample the quality and movement of the potential pollutants. Sampling and analysis procedures are presented in following paragraphs.

There are a number of existing monitor wells in the alluvium of Southam Canyon (Figure 2-1). Wells G-4A and AG-7 are upstream from the proposed spent-shale pile. Wells G-2A, G-1A, and AG-6 are downstream of the spent-shale pile, and well AG-3 is along a tributary to the main drainage in Southam Canyon.

Initial drilling and geophysical studies will characterize the Southam Canyon alluvium and identify the content of any saturated layers. If saturated layers are observed, the following array of monitor wells is proposed (Figure 2-10):

- Four wells downstream from the Phase II retention reservoir
- One well in the main Southam Canyon drainage channel upstream of the retention reservoir
- Four wells along smaller drainages associated with the processed-shale pile.

Procedures for constructing monitor wells were discussed earlier.

Water samples are probably best collected by installation of suitable submersible pumps. After well development, a submersible pump should be installed and field tests performed during continuous pumping for several hours or days. Temperature, electrical conductivity, and pH of the discharged water could be measured. After completion of this phase, a determination should be made as to the length of pumping necessary before collection of a water sample. In locations with small water yields, water samples may be collected via bailing. At least two or three well volumes should be pumped or bailed before sample collection. This procedure will allow collection of water samples typical of the alluvium near the monitor well.

Sample collection should include field measurement of pH, specific conductance, and oxidation-reduction potential (Eh). Water samples should be filtered and preserved at the time of collection (U.S. Environmental Protection Agency, 1972; U.S. Geological Survey, 1970). Laboratory analyses are presented in Table 2-7. The priority measures listed here are taken from the preliminary priority ranking developed in Slawson (1979). It is recommended that initial monitoring include at least the constituents listed as having high and intermediate priority in the highest priority analysis category.

Appropriate sampling frequencies should be developed during the initial sampling program and adjusted in response to changes in water quality. Initially, depth to water and field measurement of pH, specific conductance, and Eh (or dissolved oxygen) should be monitored on a monthly basis. More detailed chemical analyses (Table 2-7) would be performed on a quarterly basis except if appreciable water quality changes are noted during the monthly sampling. Sampling frequency should be reevaluated at least after each sampling year.

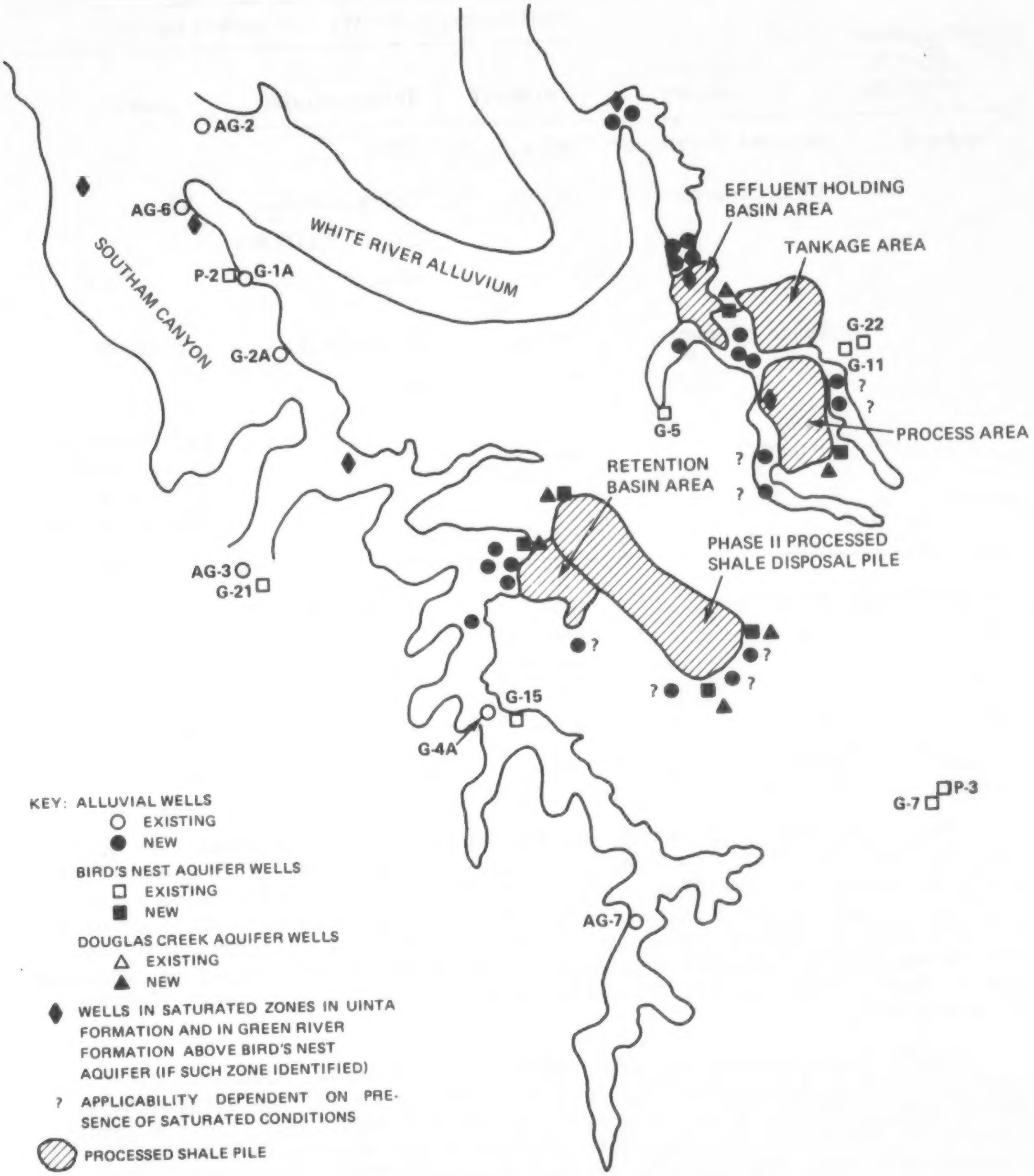

AG-2
AG-6
P-2
G-1A
G-2A
SOUTHAM CANYON
WHITE RIVER ALLUVIUM
EFFLUENT HOLDING BASIN AREA
TANKAGE AREA
G-22
G-11
G-5
PROCESS AREA
RETENTION BASIN AREA
PHASE II PROCESSED SHALE DISPOSAL PILE
AG-3
G-21
G-15
G-4A
G-7
P-3
AG-7
?
KEY: ALLUVIAL WELLS
○ EXISTING
● NEW
BIRD'S NEST AQUIFER WELLS
□ EXISTING
■ NEW
DOUGLAS CREEK AQUIFER WELLS
△ EXISTING
▲ NEW
◆ WELLS IN SATURATED ZONES IN UINTA FORMATION AND IN GREEN RIVER FORMATION ABOVE BIRD'S NEST AQUIFER (IF SUCH ZONE IDENTIFIED)
? APPLICABILITY DEPENDENT ON PRESENCE OF SATURATED CONDITIONS
▨ PROCESSED SHALE PILE

Figure 2-10. Map showing Phase II monitoring well sites.

TABLE 2-7. OUTLINE OF PRELIMINARY CHEMICAL ANALYSIS PROGRAM FOR MONITORING PROCESSED-SHALE DISPOSAL AREA

Analysis category priority	Analysis category	Monitoring priority for constituents		
		Highest	Intermediate	Lowest
Highest	General paramaters	pH,e.c.,Eh	TDS	--
	Major inorganics	Na,SO_4,Cl	Ca,Mg,K,HCO_3, CO_3,F, Sulfides NH_3	NO_3
	Trace elements	As,Se,Mo	Zn,Cd,Hg,B, Ni	Pb,Cu,Fe
	Organics	DOC		DOC fractionation, phenolics, specific compounds (BAP)
Intermediate	Radiological	gross α activity gross β activity	Ra-226,228	U,Th
Lowest	Bacteriological	TPC	TC	FC

Phases III and IV operation--As discussed for Phase II monitoring, periodic surface resistivity surveys and field sampling of test-hole piezometers would be appropriate for Phases III and IV for detecting and tracing water quality changes in the alluvium. The results of these surveys would be used for placement of monitor wells for direct monitoring of pollutant mobility. One survey before Phase III expansion of the disposal area should be conducted and at least annual surveys thereafter depending on the experience of Phase II operations.

Should these surveys indicate leachate formation and movement, direct monitoring of pollutant mobility should be through wells. Existing monitor wells G-2A, G-1A, and AG-6 would still be present downstream from the spent-shale pile and retention reservoir. Test-hole piezometers should also be sampled, and more complete chemical analyses performed. Additional wells would be needed immediately downstream of the spent-shale pile and above the retention dam, as well as upstream from the spent-shale pile (Figure 2-11), as follows:

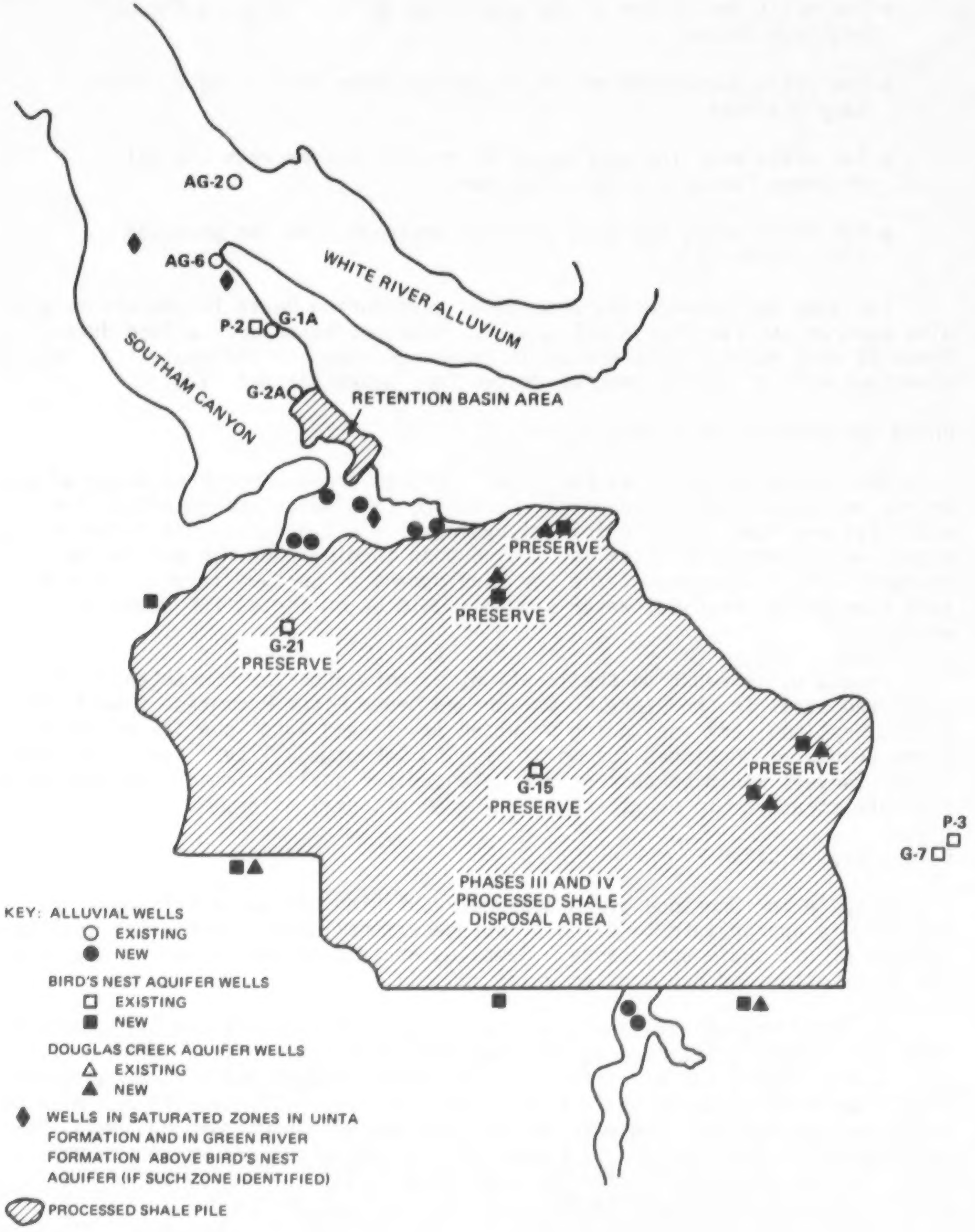

AG-2
AG-6
WHITE RIVER ALLUVIUM
P-2
G-1A
SOUTHAM CANYON
G-2A
RETENTION BASIN AREA
PRESERVE
PRESERVE
G-21
PRESERVE
PRESERVE
G-15
PRESERVE
P-3
G-7
PHASES III AND IV
PROCESSED SHALE
DISPOSAL AREA
KEY: ALLUVIAL WELLS
○ EXISTING
● NEW
BIRD'S NEST AQUIFER WELLS
□ EXISTING
■ NEW
DOUGLAS CREEK AQUIFER WELLS
△ EXISTING
▲ NEW
◆ WELLS IN SATURATED ZONES IN UINTA FORMATION AND IN GREEN RIVER FORMATION ABOVE BIRD'S NEST AQUIFER (IF SUCH ZONE IDENTIFIED)
▨ PROCESSED SHALE PILE

Figure 2-11. Map showing Phases III and IV monitoring well sites.

- Two wells downstream of the processed-shale pile along the main drainage channel
- Two wells downstream of the processed-shale pile along a tributary drainage
- Two wells near the confluence of this tributary with the main drainage (above the retention dam)
- Two wells along the main drainage upstream from the proposed spent-shale pile.

The same well-monitoring procedures used during Phase II operations are also appropriate for Phases III and IV. However, experience gained during Phase II with regard to selection of sampling frequency and analytical determinations will guide the program design for Phases III and IV.

Unita and Green River Formations--

Monitoring in the Uinta Formation includes areas beneath or downgradient of the processed-shale pile where fracturing (and hence the potential for mobility) are identified in initial hydrogeological surveys. In these areas, access wells should be installed and neutron logging used for monitoring changes in moisture content and the development of perched layers. Should such changes be observed, water samples would be collected for chemical analysis.

Depending somewhat on the location, extent, and flow characteristics of saturated zones in the Uinta Formation and Green River Formation (above the Bird's Nest Aquifer) monitoring of water levels and water quality of these zones should be continued for monitoring pollutant mobility. Annual or semi-annual surveys would be appropriate unless water quality impacts were detected in these strata or in overlying alluvium or disposal piles.

Bird's Nest Aquifer--

Despite the presence of an apparent confining bed above this aquifer, sampling is appropriate to allow direct determination of groundwater quality effects of oil shale operations. Sampling would be accomplished through the use of existing and new monitor wells.

Phase II operations--There are two existing wells (P-3 and G-7) about 1 mile generally upgradient from the proposed spent-shale pile (Figure 2-1). Well G-15 is about 1/2 mile from, and is neither upgradient nor downgradient from, the proposed spent-shale pile. Wells G-5 and G-21 are within 1 mile of the proposed reservoir and pile but are not upgradient or downgradient. Depending on economic factors, a number of monitoring designs may be appropriate. The following are listed in order of priority for inclusion in the monitoring program (Figure 2-10):

- One additional well downgradient of the spent-shale pile

- One additional well downgradient of the retention reservoir

- Two additional wells upgradient of the processed-shale pile.

Because additional data are necessary to determine aquifer characteristics of the Bird's Nest Aquifer, the wells should be constructed so as to permit aquifer testing. Such wells should be a large-diameter (e.g., 14-inch) hole drilled to the base of the Bird's Nest Aquifer. This would allow an 8-inch-diameter PVC casing to be installed to the bottom of the hole; the casing should be perforated opposite the Bird's Nest Aquifer. Clean pea gravel of known composition should be used to pack the well. The well should be properly sealed at the ground surface at the top of the Bird's Nest Aquifer, during drilling and developed properly.

The same sampling methods and program for water quality analysis should be followed as for wells in the alluvium. The frequency of sampling should be quarterly for the first year. Thereafter, the frequency can be altered based on previous experience. It is likely that annual sampling would be sufficient if proper sampling procedures are established.

Phases III and IV operation--Existing wells G-15 and G-21 and the four proposed new monitor wells in the Bird's Nest Aquifer are in the area to be covered with spent shale in Phases III and IV. These wells can be preserved by extending the casing upward as the spent shale is placed. However, extreme care must be taken to prevent damage to the casing. Existing wells P-3 and G-7 are upgradient, and P-2 is downgradient, of the proposed pile. Considering the large size of the spent-shale pile, construction of a number of new wells is appropriate. For purposes of this phase of the monitoring design, four additional wells are proposed, all of which would be along the periphery of the spent-shale pile.

Well construction, sampling, and analysis programs for Phases III and IV are presented above. However, the experience gained from monitoring the Phase II spent-shale pile and retention reservoir should be used, particularly for determination of sampling frequency and selection of analytical determinations.

Douglas Creek Aquifer--

Despite the relatively great depth of this aquifer, sampling is necessary because Douglas Creek is potentially a major aquifer and because hydraulic head relations and flow between the Bird's Nest Aquifer and groundwater in the Douglas Creek Member is poorly known at present.

Phase II operation--There are no wells effectively tapping the Douglas Creek Aquifer within 3 miles of the proposed spent-shale pile. Additional wells are thus needed to adequately monitor this aquifer (Figure 2-10):

- One additional well downgradient of the processed-shale pile

- One additional well downgradient of the retention dam

- Two additional wells upgradient of the processed-shale pile.

These are listed here in decreasing order of priority for inclusion in the monitoring program. The wells should be spaced to allow determination of flow patterns.

Because additional data are needed on the aquifer characteristics of the Douglas Creek Aquifer, the wells should be constructed so as to allow aquifer testing. Similar construction techniques should be followed as for the proposed new monitor wells in the Bird's Nest Aquifer. However, in this case, the casing should be perforated opposite the Douglas Creek Aquifer. The well should be gravel packed opposite this interval and bentonite or cement added opposite the Bird's Nest Aquifer so that interaquifer flow does not occur. The large voids in this aquifer indicate that cement may be the preferred sealant material.

The preceding discussions on sampling methods, sampling frequency, and analytical program for the Bird's Nest Aquifer are also appropriate for monitoring the Douglas Creek Aquifer.

Phases III and IV operation--Monitoring in the Douglas Creek Aquifer during Phases III and IV can be accomplished by preservation and upward extension of the casing of wells constructed for Phase II monitoring. Considering the large size of the Phases III and IV spent-shale pile, construction of additional wells may be appropriate. Two additional wells along the periphery of the disposal pile (Figure 2-11) would be adequate for this purpose.

Well construction techniques, sampling procedures, frequency, and chemical analysis presented for Phase II monitoring is also appropriate here.

Summary of Monitoring Development Activities

Monitoring program development activities for the processed-shale disposal area are summarized in Table 2-8. The various proposed activities are also ranked relative to their priority for developing an effective monitoring program. Cost of implementation and the results of initial monitoring within the disposal pile will determine the ultimate selection of monitoring activities. Estimates of annual costs for the activities outlined in Table 2-8 are summarized in Table 2-9. Details of these cost items are presented in Appendix B of this report.

The combination of the priority ranking of the monitoring activities (and potential pollution source) and costing data provide a framework for developing an effective monitoring program given defined budgetary constraints. For each of the methodology steps, monitoring program activities are listed in Table 2-8 in the order of relative priority or importance for monitoring design and for monitoring of groundwater quality impacts. With regard to trade-offs between activities for different monitoring steps, the table should be interpreted to mean that highest ranked items for one step have relatively greater priority than lower ranked items for other steps.

TABLE 2-8. SUMMARY OF MONITORING PROGRAM DEVELOPMENT ACTIVITIES FOR THE PROCESSED-SHALE DISPOSAL AREA AND PRIORITIES FOR ACCOMPLISHING THOSE ACTIVITIES

	Monitoring step				
Priority	Pollutant source characterization	Water use	Hydrogeology and water quality	Infiltration	Pollutant mobility
Highest	Surveys of development activities Waste chemical analyses: -- General -- Major inorganic -- Trace metals -- Organics		Alluvium: -- Geophysical surveys and test holes -- Sample new wells -- Pump tests at new wells -- Determine flow patterns Uinta and Green River Formations: -- Geologic mapping (e.g., fractures) -- Identification and characterization of saturated zones near mouth of Southam Canyon Bird's Nest Aquifer: -- Evaluate sampling methods	Infiltrometer tests Sensor evaluations	Monitoring in processed-shale pile Monitoring in alluvium
Intermediate		Regional surveys	Alluvium: -- Water quality sampling at existing wells		Monitoring in Uinta Formation and Green River Formation above the Bird's Nest Aquifer
Lowest	Waste chemical analyses: -- Radiological -- Bacteriological		Bird's Nest and Douglas Creek Aquifers -- Test existing wells -- Install and test new wells		Monitoring in Bird's Nest Aquifer and Douglas Creek Aquifer

TABLE 2-9. PRELIMINARY COST ESTIMATES FOR MONITORING PROGRAM ACTIVITIES DESCRIBED IN TABLE 2-8 FOR PROCESSED-SHALE DISPOSAL AREA

Assigned monitoring priority	Phase and year of development	Cost estimate (annual costs in thousands of 1978 dollars) for each monitoring step				
		Pollutant source characterization	Water use	Hydrogeology and water quality	Infiltration	Pollutant mobility
Highest	Phase II:					
	Initial year:	57	0	83	19	15
	Thereafter:	9	0	0	0	21
	Phase III:					
	Initial year:	57	0	21	3	26
	Thereafter:	9	0	0	0	27
	Phase IV:					
	Initial year:	8	0	2	0	26
	Thereafter:	3	0	0	0	22
Intermediate	Phase II:					
	Initial year:	0	1	8	0	6
	Thereafter:	0	1	6	0	<4
	Phase III:					
	Initial year:	0	1	3	0	5
	Thereafter:	0	1	3	0	<4
	Phase IV:					
	Initial year:	0	1	0	0	5
	Thereafter:	0	1	0	0	<4
Lowest	Phase II:					
	Initial year:	8	0	370	0	5
	Thereafter:	8	0	0	0	3
	Phase III:					
	Initial year:	8	0	219	0	8
	Thereafter:	8	0	0	0	5
	Phase IV:					
	Initial year:	2	0	0	0	5
	Thereafter:	2	0	0	0	5

This does not mean that low ranked items (e.g., new Bird's Nest Aquifer wells) should not be included in the monitoring plan or that existing monitoring (e.g., in the deep aquifers) is completely adequate.

SECTION 3

MONITORING DESIGN DEVELOPMENT FOR THE PROCESS AREA

INTRODUCTION

The process area is contained in a watershed northeast of the processed-shale disposal area located in the Southam Canyon drainage (Figure 1-2). Potential pollution sources in the process area include a waste-water holding pond, raw shale storage, tankage area, miscellaneous process and waste streams, and surface disturbances (Figure 3-1). The nature of these sources is described in Slawson (1979) along with a priority ranking of these sources (Table 3-1). Much of the information on proposed monitoring and alternative monitoring approaches discussed in Section 2 for the processed-shale disposal area are also applicable to the process area. These discussions will not be repeated here.

PROPOSED OR EXISTING MONITORING PROGRAMS

Proposed or existing monitoring programs are described in Figure 2-1 and Table 2-2. Groundwater monitoring plans include quarterly sampling of water quality in the Bird's Nest Aquifer beneath the tankage area and water-level monitoring to the west of the process area. Monitoring within the plant or treatment facilities by tract developers has not been specified at this time.

MONITORING DEFICIENCIES

Perceived monitoring deficiencies in the process area include background information needed for the design of a cost-effective groundwater quality monitoring program (e.g., data on pollutant-source characteristics and site hydrogeology) and capabilities for monitoring pollutant mobility.

Pollutant-Source Characterization

Source Characteristics--

The general characteristics of the potential pollution sources associated with the process area are known. This is true for much of the tankage area (e.g., fuels, oil additives, etc.) and for many of the process waste streams. Other potential sources may be subject to greater variability in characteristics and thus are less well characterized. The effluent holding-pond water and storm water runoff are examples of this type of source. Source characterization efforts that may be associated with implementing a monitoring program in the process area include the following:

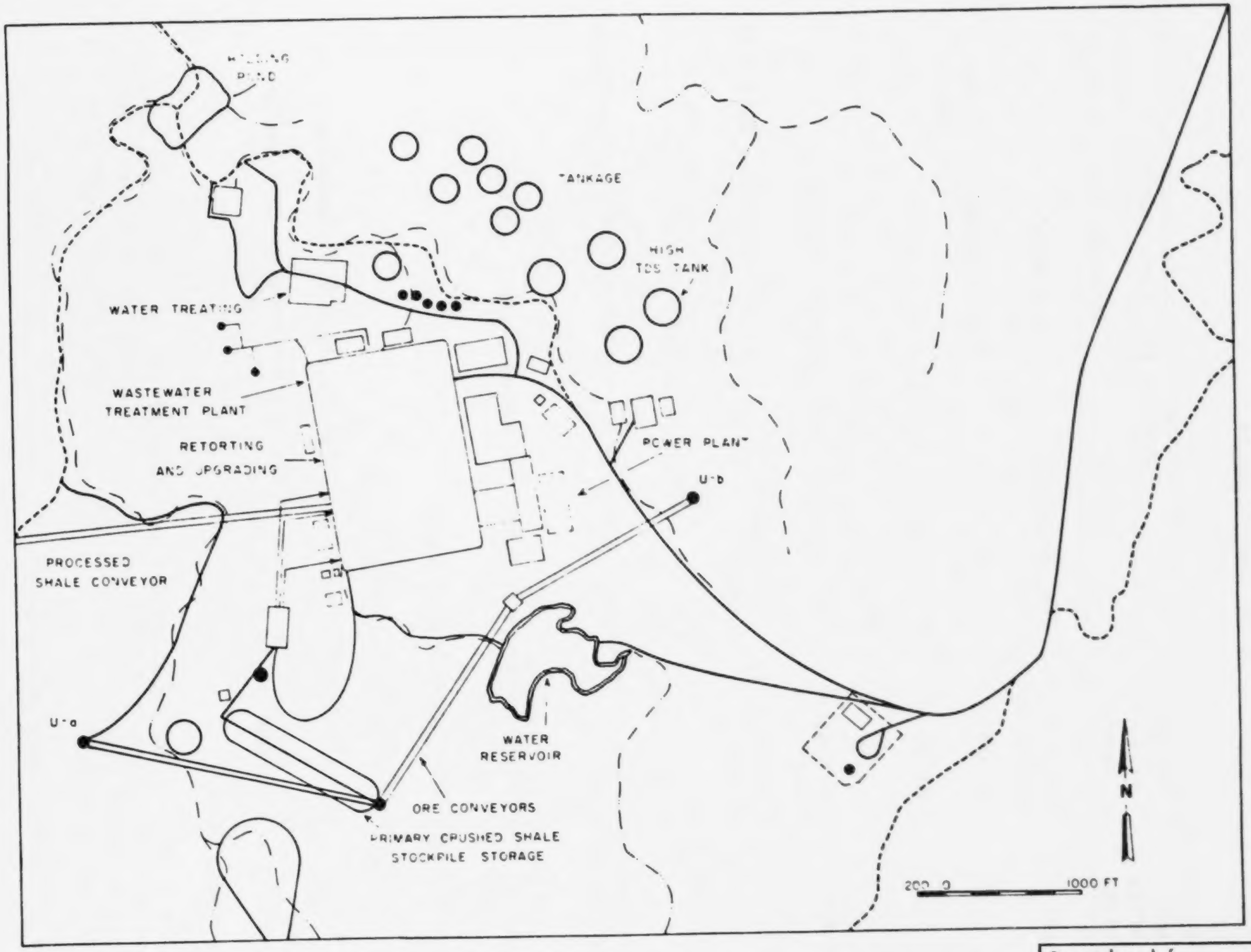

HOLDING POND
TANKAGE
HIGH TDS TANK
WATER TREATING
WASTEWATER TREATMENT PLANT
RETORTING AND UPGRADING
POWER PLANT
U-b
PROCESSED SHALE CONVEYOR
U-a
WATER RESERVOIR
ORE CONVEYORS
PRIMARY CRUSHED SHALE STOCKPILE STORAGE
N
200 0 1000 FT

Figure 3-1. Process area for Oil Shale Tracts U-a and U-b.

Reproduced from best available copy.

TABLE 3-1. PRELIMINARY RANKING OF POLLUTANT SOURCES IN THE PROCESS AREA[a]

Source Priority ranking	Potential pollution source	Potential pollutant ranging		
		Highest	Intermediate	Lowest
Highest	Effluent holding pond	TDS, organics	Trace metals, nutrients	---
	Raw shale	TDS, As, Se, organics	Major inorganics	Trace metals
	Tankage area	Miscellaneous fuels, oil additivies, ammonia	---	---
Intermediate	Storm water runoff	TDS, organics	Major inorganics	---
	Process waste streams	TDS, organics, ammonia	Major inorganics, trace metals	Nutrients
Lowest	Surface disturbance	Calcium salts, TDS	Major inorganics	---

[a] From Slawson (1979)

- Characteristics of waste products (including spatial and temporal variability)
  - -- Waste-water holding pond water
  - -- Storm water runoff
- Runoff and leaching of raw shale stockpiles and soils stockpiles.

Many of the waste streams present in the process area are utilized or disposed of in the spent-shale disposal area (see Section 2).

Development Plans--

The details of construction and operation of the various process-area facilities will greatly influence the monitoring needs for this area. Design features that need clarification prior to finalizing a monitoring program include the following:

- Effluent holding pond design
  - -- Depth-area-volume relationship

  - -- Sealants used, if any
  - -- Design of pond retention dam

- Details of chemical and flow monitoring conducted by plant operators for purpose of process control

- Runoff control design features (diversions, dikes, culverts, etc.)
  - -- Process pad area
  - -- Tankage area
  - -- Stockpile (soil and raw shale).

Water Use

The need for periodic reevaluation of project region water use, as discussed in Section 2, is also applicable to the process area.

Hydrogeologic Framework and Existing Water Quality

Basic categories of data deficiency for the hydrogeologic framework and existing groundwater quality in the process area are essentially those presented for the processed-shale disposal area (Section 2). Specific information needs in the process area are as follows:

- Characterization of the alluvium of the process area
  - -- Thickness and subsurface extent
  - -- Presence of saturated layers and groundwater flow patterns
  - -- Aquifer characteristics (transmissivity, storage coefficient, water quality

- Presence and characteristics of saturated zones in the Uinta Formation and the Green River Formation above the Bird's Nest Aquifer

- Aquifer characteristics of Bird's Nest Aquifer and Douglas Creek Aquifer under the process area
  - -- Transmissivity
  - -- Groundwater flow patterns
  - -- Storage coefficient
  - -- Water quality.

At present, the hydrogeology and groundwater quality of the process area have not been directly measured or have only been partially sampled.

Infiltration

Infiltration in the process area through the surface of soils, alluvium, and the Uinta Formation is an important hydrologic process for evaluating potential pollutant mobility. Direct measurement of infiltration in the process area was not included in baseline studies. Specific sites for consideration of infiltration potential include:

- Waste-water holding pond
- Various tankage sites
- Areas adjacent to plant pads
- Raw shale storage area
- Water supply storage area.

Pollutant Mobility

The general features of the discussion of pollutant mobility monitoring deficiencies presented for the processed-shale disposal area are also relevant here. In general, the White River Shale Project proposes no source monitoring, vadose zone monitoring, or direct determination of infiltration potential. The rationale is that sampling of wells alone can provide adequate information. However, because of the probably long travel times of percolating water in the vadose zone and saturated zone, decades may elapse before pollutants reach wells. In addition, in order to interpret water sampling from wells, the entire sequence of events from the land surface to the well discharge must be understood.

Summary of Monitoring Deficiencies

Uncertainties exist in information on source characteristics, in details of disposal and other operational plans, in knowledge of the hydrogeologic framework, and in sampling and projecting mobility of potential pollutants. Many monitoring deficiencies result from the proposed utilization of existing wells that were not drilled for this purpose. Table 3-2 presents a summary and relative priority ranking or monitoring deficiencies in each of the monitoring methodology steps. Monitoring deficiencies for each of the methodology steps are listed in order of relative priority for monitoring program development. With regard to trade-offs between methodology steps, the table should be interpreted to mean that highest-ranked items for one methodology step have relatively greater priority than lower ranked items for other steps.

TABLE 3-2. RELATIVE PRIORITY RANKING OF MONITORING AND INFORMATION DEFICIENCIES IDENTIFIED FOR THE PROCESS AREA

Relative priority ranking	Monitoring methodology steps				
	Pollutant-source characterization	Water use	Hydrogeologic framework and existing water quality	Infiltration	Pollutant mobility
Highest	Design and construction procedures -- Waste-water holding basin -- Runoff control and diversion		Characterization of alluvial streams	Seepage from holding or storage basins	Mobility in soils and alluvium
	Process monitoring plans			Infiltration in tankage and raw shale storage	
	Source chemical characteristics -- Holding ponds -- Runoff and leacate in stockpiles -- Product and process waste streams	Regional water use survey	Survey of fracturing in Uinta Formation Characteristics of saturated zones in Uinta Formation and Green River Formation above the Bird's Nest Aquifer	Infiltration in Uinta Formation	Mobility in Uinta Formation or Green River Formation above the Bird's Nest Aquifer
Lowest			Aquifer testing in deep aquifers		Mobility in deep aquifers

ALTERNATIVE MONITORING APPROACHES

Pollutant-Source Characterization

Data deficiencies for pollutant-source characterization include analyses of holding pond and process-area runoff waters, process and product stream monitoring plans, and details of construction of the holding pond and runoff control structures.

Alternative Approaches--

The characteristics (including spatial and temporal variability) of effluent-holding pond waters and process-area runoff waters could be evaluated through the use of simulation models. Although such models could be formulated, data do not exist at this time to adequately calibrate and validate the models. Hence a direct sampling approach is probably needed to characterize these sources.

Alternative approaches for examining the details of construction include obtaining blueprints or other drawings from tract developers and onsite examination during site development. Clearly, direct interaction with tract developers would be an asset for implementation of either or both approaches. Specific items of interest are:

- Construction of retention dike for waste-water holding pond (materials used, construction of cutoff wall, etc.)
- Pond construction (excavation depth--e.g., to bedrock--sealants used, survey of pond dimensions)
- Clearing and construction in general plant area and tankage area (depth of excavation, nature of diking or diversions, etc.)
- Runoff diversions in raw shale storage and soil-stockpile areas
- Design and operation of waste-water treatment plant (e.g., lining of basins, elevation of 100-year flood line, etc.)
- Plans by developers for monitoring the characteristics of product and waste streams.

Characterization of contents of waste-water holding pond, runoff from the process area, and the various other waste streams that lead to the holding pond is needed to adequately assess potential pollution from the process area. This assessment is, in turn, needed to develop a cost-effective monitoring program for the process area. Alternatives for sampling the various process and waste streams include grab sampling, composite sampling, and continuous sampling (e.g., in-place conductivity or other sensors).

Sampling Frequency--

Sampling frequency requirements for pollutant-source characterization are determined by the variability of the waste-product characteristics (see Section 2).

As previously discussed, maximum "operation variability" can be expected during the initial stages of development Phases II, III, and IV as defined by the White River Shale Project (1976). Hence, maximum waste-product sampling frequency will be required during these initial stages. Once steady-state operation is achieved, sampling frequencies can be decreased significantly. The role of initial intensive sampling would be not only to define appropriate frequencies but also to define an operational range of waste-product characteristics. Decisions with regard to sampling frequency should be specific for each waste product to be characterized and will also be dependent upon plans for process-stream sampling by tract developers.

Sampling of runoff from natural precipitation of pad-washing operations will naturally be governed by the frequency of occurrence of these events. Initially, an effort should probably be made to sample all runoff events.

From these initial data and the observed variability in the analytical results between events, the sampling program can be finalized.

Analytical Methods--

Alternative sampling approaches are listed in Table 3-3. More detailed listings of possible chemical analyses are provided in Table 2-6. In addition to these analyses of potential liquid pollution sources, analyses of samples from stockpiles of soil and raw shale can be undertaken to characterize these sources. Alternative analyses of solids are outlined in Section 2 (Table 2-4) and include the following:

- Particle-size analysis (sieving and hydrometer methods)
- X-ray diffraction analysis
- Surface area

TABLE 3-3. CHEMICAL SAMPLING ALTERNATIVES FOR PROCESS AREA SOURCE CHARACTERIZATION

Potential source	Potential applicability of analyses Major inorganic	 Trace elements	 Organics
Holding pond	X	X	X
Sewage treatment plant effluent	X		X
Sour water	X	X	
Wash water from plant area and shops	X		X
Tankage retention basins	X	X	X
Precipitation runoff:			
– raw shale storage	X	X	X
– soils stockpiles	X	X	
– miscellaneous materials stockpiles	X	X	

- Water content (1/2 atmosphere, 15 atmospheres, and in-situ measurements)

- Base exchange capacity

- Cation exchange capacity

- Hydrous oxides

- Saturated extract analysis (major inorganics, trace metals, organics)

- Beaker-shaker or column tests (leachate characterization).

The discussion in Section 2 of analytical alternatives and the information to be obtained from the various analyses is also applicable to this evaluation of the process area.

In addition, operation data from the waste-water treatment plant may be needed to evaluate this source. Beyond the items discussed above, the following data may be relevant: flow rates; incoming and effluent BOD and COD; DO; temperature; total suspended solids; mixed liquor suspended solids (MLSS), if applicable; and sludge volume index (SVI), if applicable. The selection is dependent upon the type of treatment processes employed.

Water Use

Water-use patterns should be periodically assessed to evaluate the extent to which water use may be affected by oil shale development. The discussions of alternative water-use surveys provided in Section 2 are also applicable to monitoring program development for the process area.

Hydrogeologic Framework and Existing Water Supply

Needed information on the hydrogeology and existing water quality in the process area and alternative approaches for addressing those needs are essentially the same as those presented in Section 2 for the processed-shale disposal area. These previous discussions are summarized in the following paragraphs for the process area.

Alternative Approaches--

Alluvium--Characterization of the alluvium of the process area may include determination of thickness, subsurface extent, physical-chemical properties, and existence and nature of saturated layers. Approaches for examination of the alluvium include:

- Drilling program
    - -- Collection of drill cuttings
    - -- Preparation of lithologic logs

  - Definition of depth of bedrock (Uinta Formation)
  - Identification of saturated zones
- Installation of sensors to examine moisture status
  - Neutron logging
  - Tensiometers
  - Soil-moisture blocks
  - Thermocouple psychrometers
  - Salinity sensors
  - Piezometers
- Geophysical methods to determine subsurface characteristics
  - Seismic refraction surveys
  - Gravity surveys
  - Surface resistivity surveys
- Measurement of aquifer characteristics to determine groundwater flow patterns.

More detailed discussion of these alternatives is presented in the discussion in Section 2 of alluvial characterization.

Uinta and Green River Formations--The existence of saturated zones in the Uinta Formation or in the Green River Formation above the Bird's Nest Aquifer is uncertain. Test drilling of the area between the process area and the White River may be appropriate to identify such zones. Additional installation of monitor wells and aquifer testing would be needed to characterize groundwater flow patterns in these zones.

Bird's Nest Aquifer--Monitor wells in the Bird's Nest Aquifer can also be constructed near the process area. The installation of alluvial wells would allow collection of supplemental data on subsurface geology, water levels, and water quality beneath the process area. Thus, present knowledge of the Bird's Nest Aquifer could be expanded. Aquifer tests have been completed on three wells in the Bird's Nest Aquifer. The small diameter of other existing wells may prohibit their use for proper aquifer testing. Well construction and aquifer test procedures for the Bird's Nest Aquifer are outlined in Section 2. Locations appropriate for such testing in the process area are upgradient from the process area and downgradient from the effluent holding pond.

Douglas Creek Aquifer--Additional monitor wells can also be developed in the Douglas Creek Aquifer to expand present knowledge of the hydrogeology of the process area.

Analytical Methods and Sampling Frequency--

Analysis procedures for soils, alluvium, and other geologic materials are as previously outlined for solid-waste characteristics (Tables 2-4 and 2-5). Water quality analyses presented in Table 2-6 are also applicable to characterization of groundwater quality in the alluvial and deep aquifer zones associated with the process area. Factors affecting selection of sampling frequency are also described in Section 2.

Infiltration

Locations where infiltration may be evaluated include the alluvium, the Uinta Formation, and the raw shale and soil stockpiles. The most important areas are probably the area around the effluent holding pond, the area immediately downgradient of the plant pads, and the tankage areas.

Alternative Approaches--

Infiltration may be evaluated by using infiltrometer tests or rainfall simulators, or by monitoring natural precipitation events. A sufficient number of test locations should be selected to overcome errors introduced by spatial variability of infiltration properties. Assessment of infiltration into raw shale or soils stockpiles can be accomplished through direct testing of stockpile areas or through construction of relatively large (e.g., 10 x 10 feet) lysimeters.

Studies of infiltration should be closely coordinated with pollutant mobility monitoring activities. Infiltration studies may be useful for isolating and evaluating zones of potential mobility such as fractures, bedding planes, clay layers, or the interface between weathered and unweathered sandstone. Infiltration plots should be located close to possible sites for monitoring pollutant mobility to assure applicability of infiltration test results to monitoring program development, but not so close as to contaminate monitoring sites. Methods for monitoring infiltration plots are presented in Section 2. Options for such monitoring include installation of access wells for neutron logging or tensiometers to evaluate unsaturated hydraulic gradients and changes in water content.

Infiltration or seepage through the bottom of the two major basins (waste-water holding basin and water supply reservoir) in the process area (Figure 3-1) may also be evaluated. The water balance for these basins may be evaluated using the following method:

1. Construct staff gage or stilling well (possibly with a recorder) to measure water level that can be related to basin storage volume

2. Measure basin inflows, discharges, evaporation, and precipitation

3. Estimate water budget from (1) and (2) and estimate seepage losses.

Because of errors in the various measurements, seepage would probably have to be appreciable to be detected by this method. Alternatives to this water-balance approach involve instrumentation of the holding basins to directly measure changes in water content below the basin. Optional approaches include neutron logging via access wells in or around the basins, installation of moisture blocks in or around the basins, and installation of tensiometers (unsaturated conditions), piezometers (saturated conditions), etc. in or around the basins. These approaches may also be applied to monitoring around any sedimentation pond associated with the waste-water treatment plant.

Sampling Frequency--

Many of the infiltration tests outlined above (e.g., infiltrometer tests) would be one-time surveys to provide an assessment of this important hydrologic process. However, infiltration monitoring activities at holding basins may be repeated occasionally or be carried on to provide a continual update of seepage from the basins. The water-balance components (input, output, and storage) could at various times be monitored for defined time periods (perhaps a week or a month) to provide a measure of seepage over that time period. Alternatively, the water-balance components could be monitored continuously to provide a measure of seepage over the entire project period.

Because rates of infiltration are not well known at present, sampling frequencies for the various alternative direct moisture measurement approaches (e.g., neutron logging or tensiometers) cannot be defined in detail. Sampling frequencies should be based on observed rates of change in subsurface moisture level. Hence, the frequency employed may vary during different seasons.

Pollutant Mobility

The monitoring of pollutant mobility deals with the detection and measurement of the movement of water and solutes in the subsurface. These monitoring efforts are closely related to infiltration monitoring. Alternatives for pollutant-source monitoring in the process area include monitoring at the land surface, in the alluvium of the process area drainage, in the Uinta Formation, in the Green River Formation above the Bird's Nest Aquifer, in the Bird's Nest Aquifer, and in the Douglas Creek Aquifer.

Indirect Sampling Approaches--

Indirect sampling methods are appropriate for use in the alluvium and possibly in the Uinta Formation of the process area. Alternative approaches are essentially those presented in Section 2. These include:

- Moisture monitoring using neutron logging, tensiometers, moisture blocks, or thermocouple psychrometers

- Salinity sensors
- Surface resistivity surveys.

These approaches can be implemented around the waste-water holding basin, tankage area, waste-water treatment facilities, water supply pond, processing facilities, and stockpile of raw shale.

Waste-water holding basin--The waste-water holding pond will be located at the northern end of the process area, within the principal wash draining the area (Figure 3-1). The pond will be excavated within the shallow alluvium, possibly on top of bedrock. A retention dike will be constructed. Storage will be provided for the 100-year flood. Flows in excess of the design flood may overtop the dike permitting flow into the downstream wash. In addition, unless the dike contains a cutoff wall, seepage may occur through the structure into the downstream alluvium. The pond will receive storm runoff and any runoff from leaking tanks (including the high-TDS tank), as well as treated waste water from the sewage treatment plant, sour water from retorting and upgrading processes, and wash water from the industrial area.

Monitoring sites can be located around the waste-water holding pond perimeter, beneath the pond liner, within the pond retention dike, and in the alluvium downstream from the holding basin. Monitoring upgradient from the basin is also appropriate to evaluate infiltration between upstream sources and the basin. Visual inspections of seepage through or around the basin retention dike can also be conducted. Results of indirect sampling surveys can be used to indicate sites and the magnitude of subsurface movement. This information can in turn be used to locate sites for water sample collection.

Tankage area--The tankage area will be located in the northeast portion of the process area (Figure 3-1). The tankage area will include storage containers for crude shale oil, naphtha, fuel oil, ammonia, diesel fuel, water from the sour water stripper, and raw water, as well as the high-TDS wastewater storage tank. The high-TDS tank will be located on an unspecified site within the tankage area. This tank will receive waste water from the following: water-supply treatment sedimentation unit, ion-exchange regenerator, cooling tower, tail-gas unit, sulfur plant, hydrogen plant, hydrotreating units, and the mines. The tankage area will be constructed on bedrock outcrops and on alluvium, draining into the proposed site of the waste-water pond. Tankage must be located within a dike network. The dike system is enplanned to be capable of containing 150 percent of the tank capacity it encloses plus the 100-year flood runoff volume from the drainage area of the tanks. Soils in the tankage area range from moderately deep in alluvial zones to nonexistent in rocky areas. The associated infiltration rates are moderate (alluvium) to very low (rocky areas).

Alternatives for implementation of the above-listed indirect sampling methods in the tankage area are within diked areas, within the dikes themselves, and in the alluvium downgradient of the tankage area. In addition, visual inspections for tank leakage, deterioration of dikes, etc. may be included in the monitoring program.

Waste-water treatment plant--According to the Detailed Development Plan (White River Shale Project, 1976), "Sanitary waste water collected from employee facilities will be routed to a sedimentation basin and then to biological oxidation treatment units. The biologically treated effluent will be disinfected and discharged to the waste-water and storm-runoff holding basin." Total expected flow of sanitary waste water is 10 gallons per minute during Phase II and 46 gallons per minute during Phases III and IV.

Detailed information on the nature of the waste-water treatment process is not included in the DDP (White River Shale Project, 1976). Thus, the sedimentation pond may be lined or unlined, or it may actually consist of a cement tank. Similarly, units for "biological oxidation treatment" may comprise trickling filters, activated sludge tanks, or extended aeration tanks. Because of the small volume expected, the latter technique will probably be used to provide secondary treatment. Details on the operation of extended aeration plants are given by Hammer (1977).

The treatment plant will be located near a small wash immediately above the tankage area. Alluvial soils within the wash are deeper than other soils in the area and are rated as having moderate infiltration rates. If the treatment plant were to be flooded by storm runoff, raw sewage could flow in the wash and eventually into the waste-water holding pond. The amount of sludge produced by the waste-water treatment plant may amount to 0.5 ton per day (dry weight) during full production. Sludge will be stored in drying beds and used as a soil conditioner in revegetation areas.

Monitoring plans for the waste-water treatment plant area depend on the final design of the plant. Alternative monitoring locations are likely to be included within or around the sedimentation pond and within the treatment plant itself. Additional sampling downgradient of the plant may be indicated should flooding or pond failure occur.

Water supply storage basin--During Phases III and IV, fresh water will be pumped from the White River reservoir to a water-supply storage basin located southeast of the processing facilities (Figure 3-1). According to the DDP (White River Shale Project, 1976):

> The on-tract freshwater storage pond will be constructed to provide operational flexibility, including 3 days' reserve and additional storage to maintain a reliable supply of water during an outage of the reservoir pumping station or pipeline and to control drainage water. Although no subsurface exploration or material testing have been performed, the pond will be formed by an earthfill dam constructed by making maximum use of local materials.

The DDP shows the site of the proposed water storage pond to be immediately south of the processing facilities, within the major wash crossing the area. The alluvial soils in the wash have moderate infiltration potential. Outside the wash, soils have very low infiltration potential. The latter soils are generally shallow, overlying bedrock.

Strictly speaking, the water storage pond is not a pollution source. However, failure of the earthen dam may lead to flooding in the downstream process area, the waste-water treatment facilities, and the tankage area. Pollutants in these areas may be solubilized or entrained in floodwater and eventually infiltrate into the shallow alluvium or discharge into the waste-water holding pond. During normal conditions, seepage from the pond may create a shallow water table in downstream alluvium, increasing the mobility of infiltrating pollutants in the process area, sewage treatment plant, and tankage area. In light of the limited pollution hazard associated with the water storage pond, the major emphasis during monitoring should be on non-sampling studies to evaluate seepage losses. However, a small-scale sampling program may also be initiated to monitor inadvertent runoff or spills into the pond.

Monitoring of this storage pond may be accomplished by implementing the previously listed indirect sampling methods within, around, or downgradient from the pond. Water-balance methods may also be applied to evaluate seepage from the basin.

Processing plant--The Phase II processing plant will include the following units: a vertical-type retort, precipitator, Stretford unit, incinerator, boiler and feed-water treatment unit, cooling towers, and secondary crusher and screening unit (White River Shale Project, 1976). Facilities associated with the Phase III and IV processing plant include: the coarse-shale reactor, fine-shale reactor, compressors, crude-shale oil hydrotreater unit, amine regenerator, hydrogen plant, naphtha hydrogen treater unit, and the sulfur plant. The waste-water treatment plant is also located within the processing facilities area; features of the treatment facilities and associated monitoring alternatives were discussed above. The generalized area in which the processing facilities will be located is shown on Figure 3-1. Note that the plant will be located on or near the wash transecting the process area.

A larger number and variety of pollutants are associated with the processing facilities. Oily waste water produced by cleaning the facilities and industrial area will be collected in a sewer. Similarly, the retorting and upgrading process will produce sour waste water containing sulfides, ammonia, phenol, and other organics. Some of this water will be stripped and reused, and the remainder will be discharged into the oil waste sewer. High-TDS water will be produced by other units, including the hydrotreating units and the fine-shale retorts. Waste water from these units will be collected in a separate sewer and stored in the high-TDS waste-water tank.

In addition to pollutants generated during normal plant operation, the danger always exists that equipment or tank failures or flooding may release liquid wastes. Runoff from such events would flow into downstream washes and eventually into shallow groundwater.

The indirect sampling methods listed above may be implemented downgradient from the plant area. This will allow sensing of changes in moisture or subsurface water movement due to runoff from the process area resulting from natural precipitation of pad-cleaning activities.

Materials stockpiles--Depending on the nature of runoff containment and diversion around raw shale and any soils stockpiles in the process area, indirect sampling methods may be implemented in these areas. Sites for locating sensors or access wells include: within the stockpiles themselves; around the periphery of the stockpiles; within containment structures; and downgradient of the stockpiles.

Direct Sampling Approaches--

Direct sampling of potential pollutant mobility in the process area may be accomplished at the surface (e.g., within holding ponds), in the alluvium, in the Unita Formation, and in the Green River Formation (Bird's Nest Aquifer and Douglas Creek Aquifer). Sampling methods can be implemented either (1) only after indirect sampling observations indicate subsurface mobility, or (2) as a regular monitoring activity. The former approach may be appropriate for monitoring in the unsaturated zones while the latter may be more appropriate for use in saturated strata.

Ponds--Sampling within ponds can be accomplished by grab sampling or by use of an automatic composite sampler. Grab sampling at the water surface can be done with a bottle or carboy. Sampling at depth within these ponds would necessitate use of Kemmerer or Van Dorn samplers.

Chemical spatial variability within the various ponds found in the process area (the waste-water holding pond, the water supply storage pond, and the sedimentation pond associated with the waste-water treatment plant) cannot be assessed at this time. Because of the relative smallness of these ponds, the spatial variability is expected to be small. However, this may need to be evaluated in order to define adequate sampling sites. This can be accomplished by either collection of samples at numerous locations wtihin the ponds for detailed chemical analysis or by field surveys using field measurement of temperature, pH, conductivity, dissolved oxygen, or specific ions (using specific-ion electrodes).

Alluvium--If ponds are underlain by alluvium, suction-cup lysimeters can be installed around the periphery in the unsaturated alluvium. Suction cups may be installed at several depths down to bedrock. Piezometer-sampling wells can be constructed within or adjacent to ponds to obtain samples from saturated strata, such as may develop at the alluvium-bedrock interface. Such wells would contain screened well points terminating in the saturated zone. Multilevel well samplers may also be useful.

Sampling sites are located within the retention dikes associated with process-area ponds and tankage areas, in the alluvium downgradient from the waste-water holding pond (including near the confluence of the process area drainage with the White River), and within diked areas of tankage and materials stockpiles.

Uinta and Green River Formations--Infiltration evaluations and indirect sampling surveys would be useful for identifying pathways of potential pollutant mobility in the Uinta Formation. Such pathways include fractures and bedding planes. Sampling equipment (e.g., suction-cup lysimeters) may be installed at sites where the potential for mobility has been identified or where changes in water content have been observed (such as from neutron logging).

Monitoring needs in saturated zones of the Uinta Formation and the Green River Formation above the Bird's Nest Aquifer would be defined after drilling and testing programs to describe these elements of the hydrogeologic system. In general, such zones would need to be monitored to detect modification of the hydrogeologic system resulting from mine-induced subsidence or filling of the White River reservoir.

Bird's Nest Aquifer--Despite the presence of an apparent confining bed above this aquifer, sampling of water may be necessary to allow direct determination of groundwater pollution. At present there are two wells (G-11 and G-22) located near the process area and another well (G-5) within 1/4 mile of the waste-water holding pond. Additional monitoring wells may be added to enhance the pollutant mobility monitoring in the process area. Possible sites for such wells include upgradient of the process area and downgradient of the waste-water holding pond. Additional characterization of the Bird's Nest Aquifer could be obtained if these new monitor wells are of sufficient size to permit aquifer testing. Well construction, aquifer testing, and water-sampling methods are outlined in Section 2.

Douglas Creek Aquifer--Only one well (P-4) at present effectively taps the Douglas Creek Aquifer. Additional wells would aid in characterizing this aquifer and its interaction with the Bird's Nest Aquifer and in monitoring the process area. Locations for these new wells would be comparable to those for new process-area wells into the Bird's Nest Aquifer. Construction, testing, and sampling procedures are presented in Section 2.

Sampling Frequency--

Sampling frequency requirements for monitoring in the process area cannot be adequately defined at this time. Frequencies would be best determined after the evaluation of the initial monitoring design steps (e.g., pollutant-source characterization, hydrogeologic framework, and infiltration) is completed and after initiation of field monitoring of moisture content and subsurface water movement. This initial assessment of potential rates of mobility would allow definition of basic sampling frequencies for pollutant mobility monitoring. These frequencies may designate the final sampling program, or the program can be designed for variable frequency sampling, depending on the nature of the observed results. Options for sampling frequency thus include:

- Sampling at all sites on a basic schedule
- Sampling certain sites (e.g., sites nearer the disposal pile) at a frequency greater than at other sites
- Sampling only in response to indicated changes in water content in the unsaturated zone

- Sampling only runoff or seepage when visually detected (e.g., at retention dikes.

Analytical Methods--

The alternative analytical methods outlined in Section 2 are also applicable to this discussion of sampling pollutant mobility in the process area.

MONITORING PROGRAM DEVELOPMENT

Pollutant-Source Characterization

Details of Development Plans--

During construction of the process area, close liaison should be established with the tract developers. This, in concert with onsite observation of tract development activities, is needed to provide the information base for monitoring program development. Specific items to be clarified include:

- Design of waste-water holding pond
    - -- Retention dike construction (materials, cutoff wall, etc.)
    - -- Pond excavation (i.e., depth-volume relationship)
    - -- Pond sealant
- Clearing and construction of tankage area
- Clearing and construction of general plant area
- Runoff control in raw shale storage area
- Developer/operator plans for monitoring characteristics of product and waste streams
- Design and operation of waste-water treatment plant.

To support monitoring evaluation of these tract development activities, blueprints or other design drawings should be obtained. Onsite observations should be documented in writing and by photographs. All of these monitoring design surveys and evaluations would take place in the early part of tract development. Initial field observations should be relatively frequent (perhaps weekly). As process area construction advances, this frequency may be extended to monthly or quarterly until construction is completed.

Source Characterization--

Waste characterization needs may be satisfied by direct sampling of the materials for chemical analyses. Recommended chemical analyses are presented later in the discussion of pollutant mobility monitoring development. Waste products to be characterized are (in decreasing order of priority):

- Waste-water holding pond
- Raw shale (saturated extract)
- Tankage products (waste and petroleum products)
- Storm-water runoff
- Process waste streams, including runoff from plant pads
- Soils stockpiles (saturated extract)
- Waste-water treatment plant streatm (e.g., sedimentation pond)
- Water-supply storage basin.

The need for the DMA to sample and characterize product and waste streams may be modified once tract developer process monitoring plans are identified.

The goal of these characterization analyses is to provide an indication of the source of pollutants should subsurface mobility be detected by the monitoring program. The data are needed to better implement environmental control procedures should subsurface mobility occur.

Sampling frequencies will vary during the course of tract development and operation. In addition, sampling frequency requirements are different for different source materials. For example, initial sampling of the waste-water holding pond and raw shale storage pile (saturated extract) is suggested to be weekly for 6 months (or approximately 25 samples). The variability between samples could then be evaluated and a frequency (e.g., quarterly) defined. Quarterly sampling of product and waste streams (including the waste-water treatment plant) may be appropriate initially and even less frequently after the systems have been characterized. Sampling of storm water runoff and plant pad washings are dependent on the frequency of these events. Soils extracts need to be analyzed only during a single survey, and annual sampling of the water supply storage basin is adequate.

Sampling of these sources will be by collection of grab samples. Field measurements of pH, electrical conductivity, dissolved oxygen (in holding ponds), and Eh. If appreciable vertical differences in these field measurements are observed in the holding ponds, then surface- as well as bottom-water samples should be collected. Otherwise surface sampling will be sufficient.

Water Use

The regional water-use surveys outlined in Section 2 are also appropriate for monitoring of the process area.

Hydrogeologic Framework and Existing Water Quality

Monitoring program development deficiencies identified for these methodology steps are characterization of the process-area alluvium, knowledge of fracturing in the Uinta Formation, information on existence and characteristics of saturated zones in the Uinta Formation and in the Green River Formation above the Bird's Nest Aquifer, and testing and sampling of the deep aquifers in the Green River formation. These items are listed here generally in descending order of priority for monitoring program development.

Characterization of Alluvium--

Recommended activities for monitoring program development are as follows:

- Geophysical surveys to define the boundary conditions of the process-area alluvium (i.e., thickness, spatial extent, etc.)
- Drilling to identify any saturated zones
- Water quality sampling in the alluvium
- Aquifer testing of saturated zones
- Determination of groundwater flow patterns.

The extent of saturated zones identified in the watershed to be occupied by the process area will dictate the number of wells that may be appropriate to monitor the alluvium. An example array of alluvial monitoring wells may include:

- Four wells downgradient from the effluent holding pond
- Four wells upgradient from the effluent holding pond (e.g., between the holding pond and the tankage area, retorting area, and waste-water treatment plant).

Construction of monitor wells would be as described in Section 2.

Uinta and Green River Formations--

Fracturing in the Uinta Formation may create pathways for the mobility of pollutants from the process area to the White River or to deep aquifers in the project region. Identification of the density and character of this fracturing is thus important for evaluating pollutant mobility and development of the monitoring program.

As the materials in the alluvial channels and canyon slopes are cleared for construction of the process area, visual surveys will be made of the surface of the Uinta Formation. Fracturing will be mapped and used for locating monitor sites for following mobility in the process area.

Test drilling in the general process area and between the process area and the White River should be undertaken to identify the presence of saturated zones in the Uinta Formation and in the Green River Formation above the Bird's Nest Aquifer. Should such zones be identified, sufficient monitor wells (at least three) should be constructed and aquifer tests conducted to determine groundwater gradients and flow characteristics.

Testing of Deep Aquifers--

Testing recommendations for deep aquifers of the Green River Formation are as follows (in descending order of priority):

- Evaluation of water quality sampling procedures at existing or proposed wells to establish suitable methods and sampling frequency

- Additional aquifer testing at existing wells

- Installation, aquifer testing, and water quality sampling of new wells in the Bird's Nest Aquifer and Douglas Creek Aquifer.

Evaluation of water quality sampling procedures is discussed in Section 2. Aquifer testing in existing wells is dependent on the size of existing casings. Such testing is appropriate in order to better define aquifer characteristics in the project region. Water quality sample collection procedures could also be evaluated as an assessment of baseline water quality data and to evaluate sampling frequency requirements for monitoring.

New monitor wells are described in more detail in the later discussion of pollutant mobility monitoring. Construction of these new wells would provide more information on the subsurface geology, water levels, aquifer characteristics, and water quality of the Bird's Nest Aquifer and Douglas Creek Aquifer in the immediate vicinity of the process area. The interrelationship between these two aquifers could also be more clearly defined. For this testing, one well in each aquifer, upgradient and downgradient of the process area, is recommended.

Infiltration

Infiltration potential should be evaluated in the process area to examine the potential for seepage from holding ponds to be constructed and from tankage areas, and infiltration in other areas disturbed by construction (e.g., around plant facilities). Infiltration should be assessed in the alluvium or soils and at the surface of the Uinta Formation. For these assessments, it is recommended that double-ring infiltrometers be employed as follows:

- Within the waste-water holding pond after excavation but before filling

- In the raw shale storage area

- Within diked tankage areas after clearing and construction

- Adjacent to plant facilities (pads)

- Within the basin to be used for the waste-water treatment plant sedimentation pond
- Within the basin to be used for the water-supply holding basin.

In conjunction with these infiltration tests, monitoring of subsurface mobility should also be pursued. This offers the opportunity to provide the infiltration assessments, to provide estimates of subsurface hydraulic conductivity, and to test various monitoring equipment (e.g., moisture blocks, suction-cup lysimeters, and neutron probes).

Pollutant Mobility

Pollutant mobility monitoring needs in the process area include monitoring of the alluvium in the process area, the Uinta Formation, and the Green River Formation including deep aquifers. These portions of the hydrologic system are listed here in generally decreasing order of priority for monitoring pollutant mobility.

The general approach for pollutant mobility monitoring in the process area is a sequence of sensing and response activities. There are significant uncertainties with regard to water movement and hence solute mobility. Initial monitoring activities will address the potential for water movement through the use of infiltration testing and subsurface moisture sensing (in the alluvium and Uinta Formation) during these tests and during natural precipitation events. If this monitoring indicates mobility, then additional direct sampling of water within the area alluvium, the Uinta Formation, and perhaps the Green River Formation may be indicated depending on the nature and extent of the indicated mobility. Finally, if appreciable pollutant mobility is sensed in these zones, more extensive monitoring in the deep aquifers may be required.

Alluvium--

Surface resistivity surveys are proposed as an indirect sampling approach for tracing potential pollutant mobility in the process-area alluvium. The alluvium is relatively thin and depth to water will thus be shallow, enhancing the utility of this approach. The alluvium should be surveyed downgradient of the waste-water holding basin and downgradient of the tankage and plant facility areas. Surveys should be conducted prior to process-area construction (only once) and annually after the initiation of project operation.

To supplement the surface resistivity, tensiometer (or piezometer) arrays (e.g., 3 tensiometers in a vertical sequence or 12 in a cubic array) should be installed in the alluvium as follows (Figure 3-2):

- Four downgradient (alluvial channel gradient) of the waste-water holding pond
- Four downgradient of the tankage area
- Four downgradient of the plant facilities.

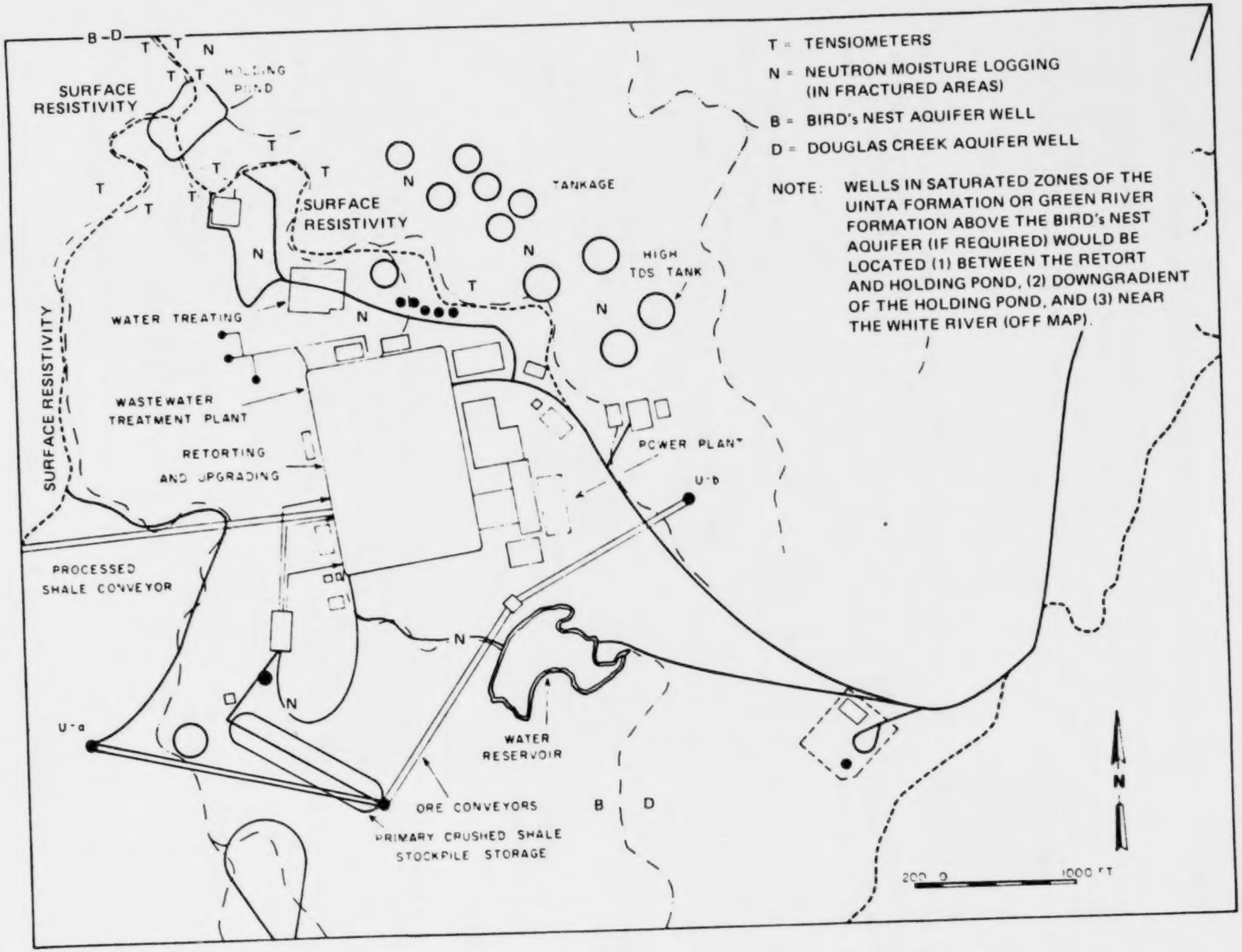

T = TENSIOMETERS
N = NEUTRON MOISTURE LOGGING (IN FRACTURED AREAS)
B = BIRD's NEST AQUIFER WELL
D = DOUGLAS CREEK AQUIFER WELL
NOTE: WELLS IN SATURATED ZONES OF THE UINTA FORMATION OR GREEN RIVER FORMATION ABOVE THE BIRD's NEST AQUIFER (IF REQUIRED) WOULD BE LOCATED (1) BETWEEN THE RETORT AND HOLDING POND, (2) DOWNGRADIENT OF THE HOLDING POND, AND (3) NEAR THE WHITE RIVER (OFF MAP).
B-D
HOLDING POND
SURFACE RESISTIVITY
SURFACE RESISTIVITY
SURFACE RESISTIVITY
TANKAGE
HIGH TDS TANK
WATER TREATING
WASTEWATER TREATMENT PLANT
RETORTING AND UPGRADING
POWER PLANT
PROCESSED SHALE CONVEYOR
U-a
U-b
WATER RESERVOIR
ORE CONVEYORS
PRIMARY CRUSHED SHALE STOCKPILE STORAGE
B
D
N
200 0 1000 FT

Figure 3-2. Pollutant mobility monitoring in the process area.

These installations should be implemented after construction is completed in each of various monitoring areas. The tensiometers could be monitored monthly to detect the changes of water content in the alluvium.

Should surface resistivity surveys or moisture monitoring indicate subsurface mobility, the survey results will be used to locate monitor wells to sample the quality and movement of potential pollutants in saturated sections. Unsaturated regions where mobility is indicated would be sampled using suction-cup lysimeters. Construction methods for alluvial monitor wells is presented in Section 2. At present there are no existing or proposed monitor wells in the alluvium of the process area. Thus monitor wells would have to be constructed. Sampling frequencies would be determined by the indicated rate of pollutant mobility, the magnitude of the pollutant mass, and the concentration detected.

Sample collection should include field measurement of pH, specific conductance, and Eh. Water samples should be filtered and preserved at the time of collection (U.S. Environmental Protection Agency, 1974; U.S. Geological Survey, 1972). Laboratory analyses are presented in Table 2-10.

Appropriate sampling frequencies should be developed during the initial sampling program. Initially, depth to water and field measurement of pH, specific conductance, and Eh should be monitored on a monthly basis. More detailed chemical analyses (Table 2-11) would be performed on a quarterly basis, unless appreciable water quality changes are noted during monthly sampling. Sampling frequency should be reevaluated after each sampling year, as a minimum.

Uinta and Green River Formations--

Initial geologic surveys and infiltration studies should be used to identify potential mobility pathways (e.g., fractures) in the Uinta Formation beneath the process area. Monitoring of the Uinta Formation would follow these potential pathways, Initially, access wells should be drilled through fractured regions, and neutron logging will be employed to monitor changes in water content and the possible formation of perched groundwater (Figure 3-2).

Should such perched groundwater be indicated, water samples would be collected by emplacing piezometers or suction-cup lysimeters. Sample analysis approaches are described in Section 2.

Test wells developed in the Uinta Formation or in the Green River Formation above the Bird's Nest Aquifer should be monitored to detect changes (including water quality) in these elements of the hydrogeologic system. Such sampling should be conducted quarterly during the initial monitoring period to define seasonal patterns and relationships with White River discharge. Evaluation of these data may allow modification of this sampling frequency.

Bird's Nest Aquifer--

Despite the apparent confining bed above this aquifer, sampling may be appropriate to allow direct determination of groundwater quality effects of oil shale operations. Sampling would be indicated should monitoring of sources, alluvium, and the Uinta Formation show the mobility of pollutants. Sampling should be accomplished through the use of existing and new monitor wells.

There are two wells (G-11 and G-22) near the tankage and plant facilities and another well (G-5) within 1/4 mile of the effluent holding pond. Additional monitor wells may be required as follows (Figure 3-2):

- One additional well downgradient of the waste-water holding basin

- One additional well upgradient of the process area.

Well construction, testing, and sampling approaches outlined for the Bird's Nest Aquifer in Section 2 are also applicable here.

Douglas Creek Aquifer--

Pollutant mobility monitoring in the other segments of the hydrogeologic regime of the process area may indicate a need to monitor the Douglas Creek Aquifer beneath the process area. At present, only one well (P-4) effectively taps the Douglas Creek Aquifer. Additional monitor wells in the process area may be located in the same areas described above for the Bird's Nest Aquifer (Figure 3-2). Well construction, testing, and sampling approaches are presented in Section 2.

Summary of Monitoring Development Activities

Monitoring program development activities for the process area are summarized in Table 3-4. The various proposed activities are also ranked relative to their priority for developing a technically effective monitoring program. Cost of implementation and the results of initial monitoring in the process area will determine the final design of the monitoring program.

Estimates of annual costs for the activities outlined in Table 3-4 are summarized in Table 3-5. Details of these cost items are presented in Appendix B.

The combination of the priority ranking of monitoring activities (based on the ranking of potential pollution sources) and the costing data provide a framework for developing an effective monitoring program given defined budgeactary constraints. For each of the methodology steps, monitoring program activities are listed in Table 3-4 in order of relative priority for monitoring design and for monitoring groundwater quality impacts. With regard to tradeoffs between activities for different monitoring steps, the table should be interpreted to mean that highest ranked items for one step have relatively greater priority than lower ranked items for other steps. This does not mean than low-ranked items (e.g., new Bird's Nest Aquifer wells) should not be included in final monitoring plans or that existing monitoring (e.g., in deep aquifers) is completely adequate.

TABLE 3-4. SUMMARY OF MONITORING PROGRAM DEVELOPMENT ACTIVITIES IN THE PROCESS AREA AND PRIORITIES FOR ACCOMPLISHING THESE ACTIVITIES

	Monitoring activity				
Priority	Pollutant-source characterization	Water use	Hydrogeology and water quality	Infiltration	Pollutant mobility
Highest	Surveys of development and construction activities		Alluvium: -- Geophysical surveys -- Drilling and water quality sampling	Infiltrometer tests: -- Holding ponds -- Tankage areas -- Stockpile areas	Monitoring in the alluvium
	Waste chemical analyses (waste-water holding pond, raw shale) -- General -- Major inorganic -- Trace metal -- Organics		Uinta and Green River Formations: -- Fracturing survey -- Identification and characterization of saturated zones Bird's Nest Aquifer -- Evaluate sampling methods		Monitoring in the Uinta Formation
Inter-mediate	Waste chemical analyses (products, runoff, soils stockpiles): -- General -- Major inorganic -- Trace metal -- Organics	Regional surveys	Alluvium: -- Aquifer tests -- Determine flow patterns	Infiltrometer tests: -- Other portions of process area	Monitoring in the Green River Formation above the Bird's Nest Aquifer
Lowest	Waste chemical analyses (water storage basin, treatment plant): -- All analysis categories All sources radiological and bacteriological analyses		Bird's Nest Aquifer and Douglas Creek Aquifer: -- Well testing and sampling		Monitoring in the Bird's Nest Aquifer and Douglas Creek Aquifer

TABLE 3-5. PRELIMINARY COST ESTIMATES FOR MONITORING PROGRAM ACTIVITIES DESCRIBED IN TABLE 3-4 FOR PROCESS AREA

Assigned monitoring priority	Phase and year of development	Cost estimate (annual costs in thousands of 1978 dollars) for each monitoring step				
		Pollutant source characterization	Water use	Hydrogeology and water quality	Infiltration	Pollutant mobility
Highest	Phase II:					
	Initial year:	20	0	56	1	32
	Thereafter:	3	0	0	0	24
	Phase III:					
	Initial year:	20	0	2	1	28
	Thereafter:	3	0	0	0	24
	Phase IV:					
	Initial year:	7	0	2	0	24
	Thereafter:	1	0	0	0	24
Intermediate	Phase II:					
	Initial year:	7	1	4	1	2
	Thereafter:	2	1	0	0	<1
	Phase III:					
	Initial year:	7	1	0	1	<1
	Thereafter:	2	1	0	0	<1
	Phase IV:					
	Initial year:	2	1	0	0	<1
	Thereafter:	2	1	0	0	<1
Lowest	Phase II:					
	Initial year:	5	0	243	0	3
	Thereafter:	3	0	0	0	2
	Phase III:					
	Initial year:	5	0	0	0	2
	Thereafter:	3	0	0	0	2
	Phase IV:					
	Initial year:	<1	0	0	0	2
	Thereafter:	<1	0	0	0	2

SECTION 4

MONITORING DESIGN DEVELOPMENT FOR THE SOUTHAM CANYON RETENTION DAMS

INTRODUCTION

The retention dams and associated basins proposed for Southam Canyon are intended to retain and collect any runoff or leachate from processed oil shale disposal in Southam Canyon. As such, the preliminary priority ranking information for the retention dams is essentially that developed for the processed-shale disposal area (Table 2-1; Slawson, 1979).

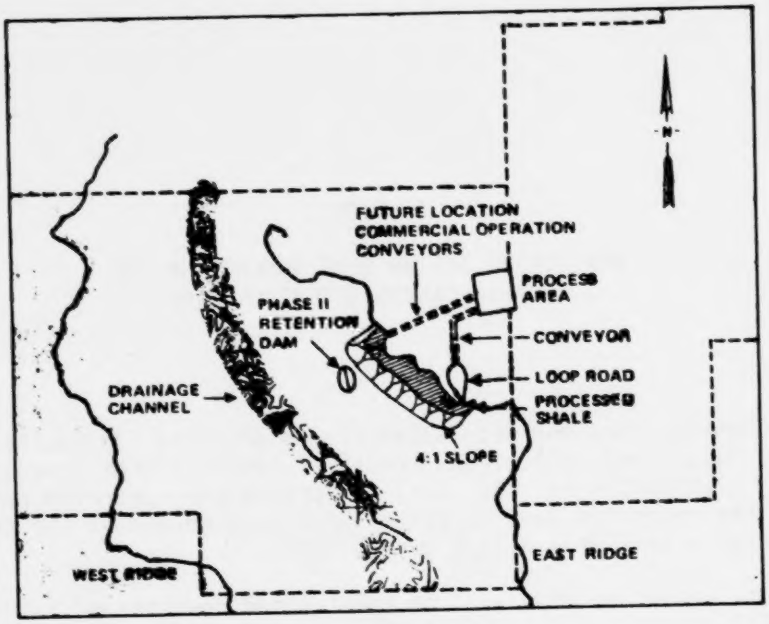
Separate retention dams will be constructed downstream of the Phase II and Phase III and IV processed-shale disposal piles (see Figure 4-1). The Phase II retention dam, constructed west of the processed-shale pile, will provide storage for the 100-year storm, in a drainage area of 500 acres (White River Shale Project, 1976). Impounded runoff will be used for dust control or compaction. If the project enters a commercial phase, the dam will be abandoned and covered by the advancing shale pile.

During the initial stages of Phase III, the Southam Canyon retention dam will be constructed near the mouth of the canyon. The purpose of this dam is to prevent runoff from the processed-shale pile entering the White River. According to the DDP (White River Shale Project, 1976), the retention dam will be an embankment-type structure, constructed with local materials, with a cutoff wall and foundation treatment to control seepage. Collected water will be used for dust control.

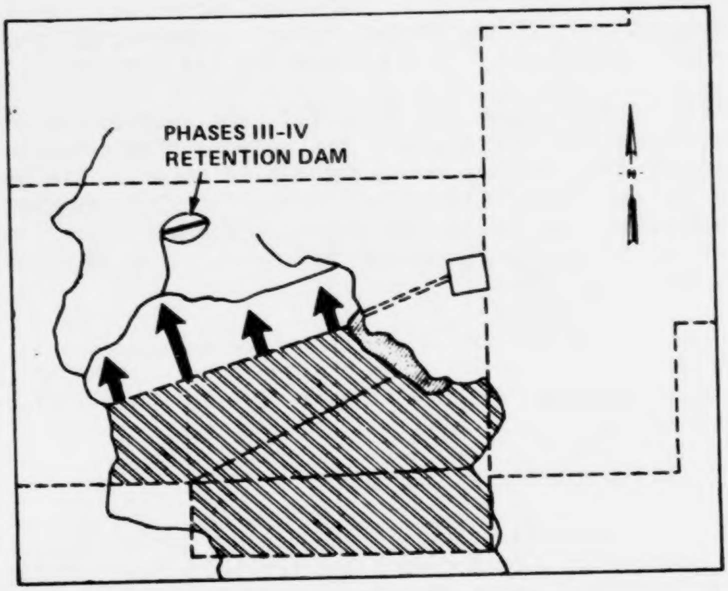
Downstream of the Southam Canyon retention dam, canyon alluvium merges with the thicker White River alluvium. After construction of the proposed White River dam, impounded water will back up into the alluvium but will not extend up to the dam.

PROPOSED OR EXISTING MONITORING PLANS

The details of montoring activities proposed by tract developers are discussed in Section 2. Monitoring plans for the retention dams include sampling of water level and water quality of ponded water. In addition, alluvial wells will be installed downstream for the retention dam as described earlier (Table 2-2 and Figure 2-3). Proposed sampling for water quality will be with a quarterly frequency, or more frequently if appreciable variability is observed. The term "appreciable" has not been defined by tract developers at this time.


N
FUTURE LOCATION
COMMERCIAL OPERATION
CONVEYORS
PROCESS
AREA
PHASE II
RETENTION
DAM
CONVEYOR
LOOP ROAD
DRAINAGE
CHANNEL
PROCESSED
SHALE
4:1 SLOPE
EAST RIDGE
WEST RIDGE

(a) Phase II


PHASES III-IV
RETENTION DAM
N

(b) Phases III and IV

Figure 4-1. Southam Canyon retention-dam sites for (a) Phase II, and (b) Phase III and IV operation (White River Shale Project, 1976).

Monitoring plans in the retention-dam areas by the White River Shale Project include obtaining groundwater from two alluvial wells and one well within the Bird's Nest Aquifer. The alluvial wells are designated G-2A and AG-6, and the deeper well is designated P-2. Well G-2A is located in NE1/4 Section 20, T10S, R24E, and is 41 feet deep. Well P-2 actually comprises two wells located in NE1/4, S20, T10S, R24E, with the upper well terminating at 378 feet and the lower well terminating at 579 feet below land surface. A surface-water gaging station, S-13, is located in SE/14, S17, T10S, R24E, near the mouth of Southam Canyon. Surface-water samples will be obtained at this gage by the White River Shale Project. The Detailed Development Plan (White River Shale Project, 1976) stipulates that surface-water samples will be collected from the retention dams quarterly when water is ponded beyond the retention dams.

MONITORING DEFICIENCIES

Pollutant-Source Charcterization

Source Characteristics--

The question of source characerization is addressed in the Section 2 discussion of monitoring of the spent-shale disposal area. In addition to these factors, characterization of waters ponded by the retention dams is advantageous for monitoring design. The proposed White River Shale Project plan includes sampling of most of the inorganic constituents suspected to be of major importance (Table 2-1). However, the temporal variability of pond water quality may not be adequately characterized with the proposed quarterly sampling frequency.

Development Plans--

The design and construction of the retention dam and associated holding pond must be known before final recommendations for monitoring can be made. Details of concern include:

- Retention dam design
  - -- Foundation
  - -- Construction of cutoff wall
- Pond design
  - -- Depth-area-volume relationship
  - -- Sealants to be used.

Water Use

The need for information on project-area water use and its influence on monitoring program development is described in Section 2.

Hydrogeologic Framework and Existing Water Quality

Monitoring information needs for characterization of the hydrogeology and water quality of Southam Canyon are described in Section 2. These previous discussions are also applicable to the retention-dams source area. In summary, the information deficiencies are as follows:

- Characterization of alluvium
  - Thickness and subsurface extent of alluvium
  - Moisture status (e.g., existence of saturated layers)
  - Spatial heterogeneity in physical properties (e.g., particle size distribution, clay content) and chemical properties (e.g., cation exchange capacity, pH, etc.)
  - Aquifer characteristics (e.g., transmissivity and storage coefficient)
  - Depth to water and direction of groundwater movement
- Soil moisture characteristic curves for alluvium, soils, and Uinta sandstones
- Fracturing in the Uinta Formation
- Occurrence of groundwater and groundwater flow in Uinta Formation and the Green River Formation above the Bird's Nest Aquifer
- Aquifer characteristics of Bird's Nest Aquifer and Douglas Creek Aquifer.

Infiltration

Infiltration potential of retention basins and the alluvial material downgradient of the retention dams should be evaluated. This would allow an assessment of the potential for seepage of collected waters from the basin and mobility in the alluvial system in the vicinity of the dams.

Some infiltration data have been collected in the vicinity of the proposed site of the retention dam for Phase III and IV operation. These baseline surveys indicated relatively low (less than 2 inches per hour) infiltration rates in general. The exact location of these infiltration plots relative to the proposed retention dam and basin needs to be clarified. The Phase II retention dam site has not been directly surveyed for infiltration potential.

The Phase II retention dam will be located in an area with soils classified hydrologically as having low-to-very-low infiltration potential. A small band of alluvial soils with moderate infiltration potential is also in the vicinity of the proposed dam. The Phase III and IV retention dam will be constructed within alluvium of the main Southam Canyon drainage channel, in soils with moderate infiltration potential.

Potential Mobility

The Section 2 discussions of pollutant mobility monitoring in Southam Canyon are generally applicable to this discussion of the retention dams. Additional monitoring deficiencies that are evident and are related to the retention dams include:

- Monitoring of unsaturated flow (and saturated flow, if detected) around the ponded area
- Monitoring of seepage through or under the dam
- Characterization of pollutant constituents that are mobile in alluvium downstream from the retention dams or in the Uinta Formation beneath the ponded area.

Summary of Monitoring Deficiencies

Uncertainties exist in monitoring design information on source characteristics, in details of disposal and other operational plans, in knowledge of the hydrogeologic framework, and in sampling and projecting the mobility of potential pollutants. Many tract-operation monitoring deficiencies result from utilization of existing wells that were not drilled for this purpose.

Table 4-1 presents a summary and relative priority ranking of monitoring deficiencies for each of these monitoring steps. The priority ranking shown here is within each monitoring step as well as between steps. Monitoring deficiencies for each of the methodology steps are listed in order of relative priority for monitoring program development. With regard to trade-offs between methodology steps, the table should be interpreted to mean that highest ranked items for one methodology step have relatively greater priority than lower ranked items for other steps.

ALTERNATIVE MONITORING APPROACHES

Alternative monitoring approaches, dealing with methodology steps that address pollutant source characterization, water use, hydrogeologic framework, water quality, infiltration, and pollutant mobility are outlined in Section 2. These approaches are also applicable to evaluation and monitoring program development for the Southam Canyon retention dams. In addition, previously presented (Section 3) alternatives for evaluating source characteristics, infiltration, and pollutant mobility at holding basins in the process area are also applicable to monitoring the Southam Canyon retention dams.

TABLE 4-1. RELATIVE PRIORITY RANKING OF MONITORING AND INFORMATION DEFICIENCIES IDENTIFIED FOR THE RETENTION-DAMS SOURCE AREA

	Monitoring methodology steps				
Relative priority ranking	Pollutant-source characterization	Water use	Hydrogeologic framework and existing water quality	Infiltration	Pollutant mobility
Highest	Retention dam design		Characterization of alluvium near retention dam sites	Infiltration within retention basins	Mobility in alluvial system
	Retention basin design		Presence and characteristics of saturated zones in the Uinta Formation and in the Bird's Nest Aquifer	Infiltration downstream from the retention dams	
		Regional water use	Characterization of fracturing in the Uinta Formation	Infiltration in Uinta Formation fractures	Mobility in the Uinta Formation and Green River Formation above deep aquifers
Lowest			Characterization of deep aquifers beneath the retention dams		Mobility in deep aquifers

MONITORING PROGRAM DEVELOPMENT

Pollutant-Source Characterization

Interaction with tract developers during the design and construction of the retention dams will be needed to finalize characterization of these potential pollution sources. Blueprints or other engineering drawings of the retention dams and the associated holding basins should be obtained initially. In addition, onsite observation during excavation and construction should be part of the characterization effort. Specific items to be clarified include:

- Nature of materials used for retention dams
- Construction details of cutoff wall
- Dimensions of retention basins behind dams (i.e., depth-volume relationship
- Sealants used in basins
- Depth of excavation for dams and retention basins.

Field observations should be supported with photographs. The frequency of field observations is dependent on the construction schedule for the retention dam.

Ponded runoff and leachate waters should be sampled by collection of grab samples at the retention dam. Field measurements should be made of water depth, pH, electrical conductivity, dissolved oxygen, and Eh. If ponded water is sufficiently deep (e.g., greater than 3 feet), surface and bottom measurement of these field-measured chemical constituents should be made. If appreciable differences are observed, then both surface- and bottom-water samples sould be collected. Otherwise, sampling at the water surface is probably sufficient. The depth measurement can be used to estimate the volume of ponded water. Water samples should be analyzed for chemical constituents listed in Table 2-10. Sampling frequency will be dictated by the presence of water in retention-dam basins.

Water Use

Regional water-use surveys outlined in Section 2 are also applicable to the monitoring program of the retention-dam source area.

Hydrogeologic Framework and Existing Water Quality

The studies of the hydrogeology of Southam Canyon outlined in Section 2 may also be used to characterize the retention-dams source area. In decreasing order of importance, these monitoring activities involve characterization of the alluvium, survey of the Uinta Formation and Upper Green River Formation, and testing and sampling of aquifers in the Green River Formation. Monitoring activities are outlined as follows:

- Characterize alluvial system in the vicinity of the retention dams by:
  - -- Geophysical surveys
  - -- Drilling and sampling of water quality
  - -- Aquifer testing of identified saturated zones
  - -- Determination of groundwater flow patterns
- Survey fracturing in the Uinta Formation in areas excavated to bedrock; identify and characterize saturated zones in Uinta Formation and in Green River Formation above deep aquifers
- Test the Bird's Nest Aquifer and Douglas Creek Aquifer by
  - -- Evaluating water quality sampling procedures
  - -- Additional aquifer testing at existing wells, where feasible

-- Installing, aquifer testing, and water quality sampling new wells.

Methods for conducting these studies are presented in Section 2.

Infiltration

Infiltration potential should be evaluated near the retention dams at the surface of the alluvium and at the surface of the Uinta Formation. Double-ring infiltrometers should be employed to evaluate infiltration within the retention basin after excavation and downgradient of the retention dam in the alluvium. In conjunction with these infiltration tests, monitoring of subsurface mobility should be employed as presented in the following discussions. This offers the opportunity to provide the infiltration assessments, to provide estimates of subsurface hydraulic conductivity, and to test various monitoring equipment (e.g., moisture blocks, suction-cup lysimeters, and neutron probes).

Pollutant Mobility

Pollutant mobility monitoring in the retention-dams source area includes (in generally decreasing order of priority) monitoring within retention dams, in the alluvial system near the dams, in the Uinta Formation, and in the Green River Formation. Because of their proximity, certain aspects of monitoring of the processed-shale disposal area (Section 2) are also included in monitoring recommendations for the retention-dams source areas. Applicable segments are presented below.

As previously discussed, the general approach for pollutant mobility monitoring is a sequence of sensing and response activities. There are significant uncertainties in this source area with regard to subsurface water and solute mobility. Initial monitoring activities should address the potential for water movements through the use of infiltration testing and subsurface moisture sensing during these tests and during natural precipitation events. If this monitoring indicates mobility, then additional direct sampling of water within the area alluvium and the Uinta Formation may be indicated depending on the nature and extent of the indicated mobility. Finally, if appreciable pollutant mobility is sensed in the Uinta Formation, more extensive monitoring in deeper zones may be required.

Retention Dams--

Monitoring of the retention dams would allow a measure of water seepage through or beneath the dams. At the time of dam construction, one to three access wells should be installed within the retention dams immediately downstream of the cutoff wall. These access wells should be installed through the dam and into the underlying Uinta Formation of perched zones if encountered (Figure 4-2). If water movement is indicated by moisture logging, piezometers (for saturated conditions, or tensiometers for unsaturated conditions) would be installed within the dam and downstream alluvium to measure pressure gradients (Figure 4-2). Proper sealing of access wells would be

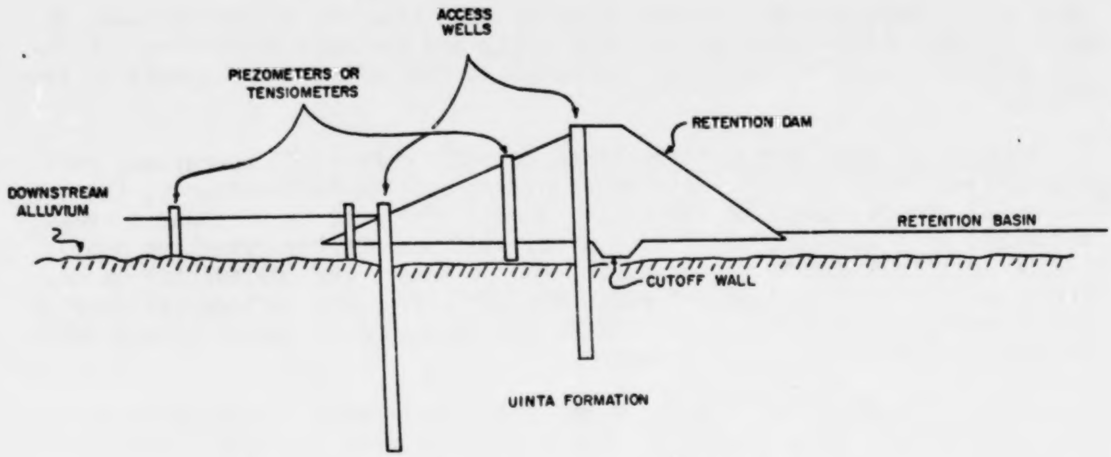


Figure 4-2. Monitoring of retention-dam sites.

critical to prevent leakage. Piezometers should contain screened well points to facilitate water sampling.

Initial moisture logging within retention dams should be on at least a monthly basis when water is (or has recently been) present in the retention basins. As a minimum, logging should be done whenever samples are collected from the pond. Monitoring of pressure gradients and water sampling would be determined by the rate of water movement. Samples should be analyzed for the chemical constitutents listed in Table 2-10.

This program is applicable to both the Phase II and Phases III and IV retention dams.

Alluvium--

Phase II operation--The applicable indirect approach for tracing the subsurface movement of high-salinity waters such as may be found in the retention basins is the use of surface resistivity surveys. The alluvium downgradient of the Phase II retention dam will be surveyed once prior to tract operation and annually thereafter. Shallow piezometers should be installed to support this data base. These surveys will be used to supplement the moisture-logging survyes proposed for the dam site.

Should surface resistivity surveys result in the positive indications of subsurface moisture movement, the survey results would be used to locate monitor wells to sample the quality and movement of the potential pollutants. Sampling and analysis procedures are presented in the following paragraphs.

There are a number of existing monitor wells in the alluvium of Southam Canyon (Figure 4-2). Wells G-4A and AG-7 are upstream from the proposed spent-shale pile. Wells G-2A, G-1A, and AG-6 are downstream of the spent-shale pile, and well AG-3 is along a tributary to the main drainage in Southam Canyon. An additional array of up to 4 wells should be installed immediately downgradient from the Phase II retention dam if the movement of potential pollutants is shown by resistivity and moisture monitoring. Alluvial well construction, testing, and sampling approaches are provided in Section 2.

Phases III and IV operation--As described for Phase II operation, periodic surface resistivity surveys would be appropriate for monitoring the Phases III and IV retention-dam source areas. The results of these surveys, in concert with moisture monitoring within and beneath the retention dam, will be used to indicate the need for, and to orient the implementation of, direct monitoring (sampling) of pollutant mobility. One surface resistivity survey should be conducted before Phase III expansion of the processed-shale disposal area and annually thereafter.

Existing monitor wells G-2A, G-1A, and AG-6 located downstream from the retention dam may be utilized for direct sampling from the alluvium. Sampling frequency will be dictated by the rate and magnitude of indicated subsurface mobility.

Uinta and Green River Formations--

As indicated above, moisture monitoring within the retention dams should extend into the Uinta Formation to detect changes in water content (and thus indicate pollutant mobility). During construction of the retention dams and basins, an assessment of fracturing in the Uinta Formation should be performed as previously described. These assessments should be supported by infiltration testing of cleared areas. In areas where the potential for mobility exists, access wells should be installed and neutron logging used for monitoring changes in moisture content and the development of perched layers. During access well drilling, it may be possible to predict where perched zones occur. Should such changes be observed, water samples should be collected for chemical analysis.

Evaluation of saturated zones in the Uinta Formation and in the Green River Formation above the deep aquifers is discussed in Section 2.

Deep Aquifers--

Despite the presence of apparent confining layers above the Bird's Nest and Douglas Creek aquifers, sampling of these aquifers may be appropriate to allow direct determination of groundwater quality effects on oil shale operations. Such sampling would be accomplished through the use of new and existing monitor wells into these aquifers.

The Bird's Nest Aquifer and Douglas Creek Aquifer are not penetrated by existing wells downgradient of the proposed retention-dam sites. Wells G-21, G-15, G-7, and P-3 are in the Bird's Nest Aquifer, upgradient at distances ranging from approximately 1 to 3 miles from the Phases III and IV retention dam. G-21 is about 1 mile to the west of the Phase II dam site. Well P-2 taps a perching layer of either the lower Uinta Formation or upper Parachute Creek Member of the Green River Formation. The Douglas Creek Aquifer is not penetrated in this source area.

Should appreciable mobility in the Uinta Formation be observed, monitoring of these deep aquifers may be inidicated. New monitor wells would be needed immediately downgradient from the retention dams. Construction, testing, and sampling of wells in the Bird's Nest Aquifer and the Douglas Creek Aquifer are presented in Section 2. Monitoring of the aquifer tapped by well P-2 would also be indicated if significant subsurface pollutant mobility is observed.

Summary of Monitoring Development Activities

Monitoring program development activities for the retention-dams source area are summarized in Table 4-2. The various proposed activities are also ranked relative to their priority for developing a technically effective monitoring program. Cost of implementation and the results of initial monitoring in this source area will determine the final design of the monitoring program.

Estimates of annual costs for the activities outlined in Table 4-2 are summaried in Table 4-3. Details of these cost items are presented in Appendix B of this report.

The combination of the priority ranking of the monitoring activities (based on the ranking of potential pollution sources) and costing data provides a framework for developing an effective monitoring program given defined budgetary constraints, as described in Sections 2 and 3.

TABLE 4-2. SUMMARY OF MONITORING PROGRAM DEVELOPMENT ACTIVITIES FOR RETENTION DAM AREAS AND PRIORITIES FOR ACCOMPLISHING THESE ACTIVITIES

	Monitoring methodology step				
Priority	Pollutant-source characterization	Water use	Hydrogeology and water quality	Infiltration	Pollutant mobility
Highest	Surveys of development activities		Alluvium: -- Geophysical surveys and test holes -- Install, test and sample new wells -- Determine flow patterns	Infiltrometer tests	Monitoring within and beneath retention dams
	Characterization of retention basin water: -- General -- Major inorganic -- Trace metals -- Organics		Uinta and Green River Formations: -- Geologic mapping -- (e.g., fractures) -- Identification and characterization of saturated zones near the mouth of Southam Canyon		
			Bird's Nest Aquifer -- Evaluate sampling methods		Monitoring in the alluvium
Intermediate		Regional surveys	Alluvium -- Water quality sampling at existing wells		Monitoring in the Uinta Formation and Green River Formation above deep aquifers
Lowest	Characterization analyses: -- Radiological -- Bacteriological -- DOC fractionation		Deep aquifers -- Test existing wells -- Install and test new wells		Monitoring in deep aquifers

TABLE 4-3. PRELIMINARY COST ESTIMATES FOR MONITORING PROGRAM ACTIVITIES DESCRIBED IN TABLE 4-2 FOR THE RETENTION-DAMS SOURCE AREA

		Cost estimate (annual costs in thousands of 1978 dollars) for each monitoring step				
Assigned monitoring priority	Phase and year of development	Pollutant source characterization	Water Use	Hydrogeology and water quality	Infiltration	Pollutant mobility
Highest	Phase II:					
	Initial year:	8	0	83	1	17
	Thereafter:	1	0	0	0	9
	Phase III:					
	Initial year:	8	0	21	1	17
	Thereafter:	1	0	0	0	9
	Phase IV:					
	Initial year:	1	0	0	0	9
	Thereafter:	1	0	0	0	9
Intermediate	Phase II:					
	Initial year:	0	1	8	0	6
	Thereafter:	0	1	6	0	1
	Phase III:					
	Initial year:	0	1	3	0	5
	Thereafter:	0	1	3	0	1
	Phase IV:					
	Initial year:	0	1	0	0	1
	Thereafter:	2	1	0	0	1
Lowest	Phase II:					
	Initial year:	1	0	370	0	6
	Thereafter:	1	0	0	0	3
	Phase III:					
	Initial year:	1	0	219	0	8
	Thereafter:	1	0	0	0	5
	Phase IV:					
	Initial year:	1	0	0	0	5
	Thereafter:	1	0	0	0	5

REFERENCES

Apgar, M.A., and D. Langmuir, "Ground-Water Pollution Potential of a Landfill Above the Water Table," Ground Water, Proceedings of NWWA-EPA National Ground Water Quality Symposium, Vol. 1, pp. 76-94, November-December 1971.

American Public Health Association, Standard Method for the Examination of Water and Wastewater, 14th Ed., 1976.

Baker, R.A., Research by the U.S. Geological Survey on Organic Materials in Water, Geological Survey Circular 744, Government Printing Office, 1976.

Bouwer, H., and R.D. Jackson, "Determining Soil Properties," Drainage for Agriculture (J. van Schilfgaarde, ed.), No. 17, Agronomy Series, American Society of Agronomy, Inc., Madison, Wisconsin, 1974.

Brown, E., M.W. Skougstad, and M.J. Fishman, "Methods for Collection and Analysis of Water Samples for Dissolved Minerals and Gases," Chapter A1, Techniques of Water-Resources Investigations of the United States Geological Survey, Book 5, Laboratory Analysis, 1970.

Day, P.R., "Particle Fractionation and Particle Size Analysis," Methods of Soil Analyses (C.A. Black, ed.), Agronomy No. 9, American Society of Agronomy, 1965.

Everett, L.G., K.D. Schmidt, R.M. Tinlin, and D.K. Todd, Monitoring Groundwater Quality: Methods and Costs, EPA-600/4-76-023, 1976.

Fenn, D.C., K.J. Hanely, and T.V. DeGeare, Use of the Water Balance Method for Predicting Leachate Generation from Solid Waste Disposal Sites, U.S. Environmental Protection Agency, EPA/530/SW-168, 1975.

Fox, J.P., D.S. Farrier, and R.E. Poulson, "Chemical Characterization and Analytical Considerations for an In-Situ Oil Shale Process Water," unpublished manuscript, 1978.

Hammer, M.J., Water and Waste-Water Technology, J. Wiley and Sons, Inc., New York, 1977.

Herbes, S.E., G.R. Southworth, and C.W. Gehns, Oak Ridge National Laboratory, Presentation at the 10th Annual Conference on Trace Substances in Environmental Health, University of Missouri, Columbia, Missouri, June 7-10, 1976.

Lee, H., T.O. Peyton, R.V. Steele, and R.K. White, Potential Radioactive Pollutants Resulting from Expanded Energy Programs, EPA-600/7-77-082, August 1977.

Loogna, G.O., The Carcinogenic Properties of Oil Shale Products and the Possibilities of Prophylaxis of Cancer, translated from Russian, U.S. Environmental Protection Agency, EPA TR76-54, 1972.

Nielsen, D.R., J.L. Starr, C. Kirda, and C. Misra, "Soil-Water and Solute Movement Studies," Isotype and Radiation Techniques in Soil Physics and Irrigation Studies, 1973, International Atomic Energy Agency, 1974.

Phillips, F.M., Pollution Source Separation, project report to General Electric-TEMPO by Water Resources Research Center, University of Arizona, Tucson, Arizona, 1977.

Slawson, G.C. (ed.), Groundwater Quality Monitoring of Western Oil Shale Development: Identification and Priority Ranking of Potential Pollution Sources, EPA-600/7-79-023, 1979.

Slawson, G.C., and T.F. Yen (eds.), Compendium Reports on Oil Shale Technology, EPA-600/7-79-039, 1979.

Smith, D.B., "Nuclear Methods," In: Facets of Hydrology (J.C. Rodda, ed.), Wiley Interscience Publication, John Wiley and Son, 1976.

Stuber, H.A., and J.A. Leenheer, "Fractionation of Organic Solutes in Oil Shale Retort Waters for Sorption Studies on Processed Shale," U.S. Geological Survey, paper presented at the ACS Fuel Sciences Division Symposium, 1978.

U.S. Environmental Protection Agency, Handbook for Analytical Quality Control in Water and Wastewater Laboratories, EPA Technology Transfer, June 1972.

U.S. Geological Survey, "Recommended Methods for Water Data Acquisition," Preliminary Report of the Federal Interagency Work Group on Designation of Standards for Water Data Acquisition, 1970.

Varma, M.M., S.G. Serdahely, and H.M. Katz, "Physiological Effects of Trace Elements and Chemicals in Water," Journal of Environmental Health, Vol. 39, No. 2, 1976.

Ward, J.C., G.A. Margheim, and G.O.G. Lof, Water Pollution Potential of Spent Oil Shale Residues, Colorado State University, EPA Water Pollution Control Research Series 14030 EDB 12/71, 1971.

Ward, J.C., G.A. Margheim, and G.O.G. Lof, Water Pollution Potential of Snowfall on Spent Oil Shale Residues, Colorado State University, Ft. Collins, Colorado Bureau of Mines Open File Report No. 20-72 (NTIS PB-210 930), 1972.

White River Shale Project, Detailed Development Plan for Federal Oil Shale Leases U-a and U-b, 1976.

APPENDIX A

ENGLISH/METRIC CONVERSIONS

1 cubic yard = 0.765 cubic meter
1 barrel = 0.160 cubic meter
1 ton (2,000 pounds) = 0.909 tonne (metric ton)
1 acre = 0.405 hectare (10,000 square meters)
1 square mile = 2.590 square kilometers
1 liquid quart = 0.946 liter
1 gallon = 3.846 liters
1 foot = 0.305 meter
1 inch = 2.54 centimeters

APPENDIX B

MONITORING COST DATA

COSTING DATA FOR SECTIONS 2, 3, AND 4

The bases of cost estimates for monitoring activities outlined in Sections 2, 3, and 4 are provided in Tables B-1, B-2, and B-3, respectively, located at the end of this appendix. In addition, the cost data for chemical analysis and for well drilling and installation are provided below.

Cost estimates for chemical analysis were taken from tables provided in Everett et al. (1976). These analytical costs assume the use of analytical methods commonly utilized by commercial laboratories (e.g., pH meter for pH, atomic absorption for metals, etc.). The need to use more sophisticated methods, such as spark source mass spectrometry or neutron activation analysis, can greatly increase costs of analysis. From recent experience with analytical laboratories, these costs were felt to be generally representative of current costs of analysis:

Category	Constituent	Estimated cost ($ per sample)
General parameters:	pH	3
	EC	3
	Eh	3
	TDS	5
Major inorganics:	Sodium	5
	Calcium	5
	Magnesium	5
	Potassium	5
	Sulfate	5
	Chloride	5
	Bicarbonate	5
	Carbonate	10
	Fluoride	20
	Sulfides	5
	Ammonia	5
Trace elements:	Arsenic	10
	Selenium	15
	Molybdenum	10
	Zinc	10
	Cadmium	10

Category	Constituent	Estimated cost ($ per sample)
Trace elements: (continued)	Mercury	10
	Boron	10
	Nickel	10
Organics:	DOC	15
	DOC fractionation	130
Radiological:	Gross alpha and beta	25
	Ra-226	30
	Uranium	18
	Thorium	25
Bacteriological:	Total plate count	7
	Total coliform	10
	Fecal coliform	10

The following assumptions were made for developing cost estimates for drilling and well installation:

- Depth of wells
  - -- Uinta Formation and Green River Formation above Bird's Nest Aquifer: 400 feet
  - -- Bird's Nest Aquifer: 600 feet
  - -- Douglas Creek Aquifer: 1,400 feet
  - -- Southam Canyon alluvium: 35 feet
  - -- Process area alluvium: 20 feet
- Drilling costs for deep wells (from Everett et al., 1976)
  - -- Base costs for 8-inch well = $14 per foot, and for 6-inch wells = $12 per foot (this latter cost used for test hole cost estimates)
  - -- These base costs are for EPA Regions III and IV, October 1974
  - -- Base costs updated for region and time using the following Engineering News Record (ENR) materials cost indices:

October 1974 ENR index:	$ 850.00
August 1978 ENR index:	1,284.00
Region III (Philadelphia) index:	200.34
Region IV (Atlanta) index:	172.97

Study area (Denver) index: $ 163.37

Average index for Regions III and IV: 186.66

-- Updated drilling costs:

6-inch well: $12 per foot (1,248/850)(186.66/163.37) or $20.13 per foot

8-inch well: $14 per foot (1,248/850)(186.66/163.37) or $23.52 per foot

- PVC casing costs (from Everett et al., 1976)

-- Base costs (Region IX, October 1974):

8-inch, $5.60 per foot

6-inch, $3.30 per foot

-- Updated cost, using regional indices for San Francisco (Region IX) and Denver (study area) of $178.41 and $163.37, respectively:

8-inch, $8.98 per foot

6-inch, $5.29 per foot

- Well logging (from Everett et al., 1976) with costs updated to present time as above

-- Bird's Nest Aquifer: $1,175 per hole

-- Douglas Creek Aquifer: 1,542 per hole

- Gravel packing and well sealing

-- Assumed $9 per yard for gravel, $50 per yard for cement sealing

-- 12-inch hole for 6-inch well, and 14-inch hole for 8-inch well

-- Hole void space to be filled is 0.07 cubic yard per foot for 8-inch well

-- Gravel packing (assume 200 feet per well): $126 per well and $162 per well for 6- and 8-inch wells, respectively (for deep wells)

-- Well sealing:

Bird's Nest Aquifer: $1,400 per well and $1,800 per well for 6- and 8-inch wells, respectively

Douglas Creek Aquifer: $4,200 per well and $5,400 per well for 6- and 8-inch wells, respectively

- Well development: assumed 4 hours per well at $85 per hour (for deep wells)
- For alluvial wells, assumed the following for processed-shale disposal area:
  - -- Drilling costs of $9 per foot and $11 per foot for 6- and 8-inch wells, respectively (the $9 per foot cost was used for alluvial test holes)
  - -- 15 feet of gravel pack and 20 feet of seal for each well, costed as above
  - -- Development time of 3 hours per well at $85 per hour
  - -- Alluvial wells in process area (20-foot well depth) are 57 percent of processed-shale disposal area wells.

COST DATA FOR TABLE 1-4

The data used for Table 1-4 costs of monitoring activities listed in Table 1-3 were taken from the cost data (Tables B-1, B-2, and B-3), as summarized below.

Pollutant Source Characterization

1. Highest (within sources), Highest (between sources) Priority: From sum of activity cost data in Tables B-1, B-2, and B-3.

2. Highest (within sources), Intermediate (between sources) Priority: For processed-shale disposal area, costing at this priority level is for 4 of the 9 sources costed in Table B-1. Hence 44 percent of Table B-1 level used here and 56 percent used for Highest (within sources), Lowest (between sources) priority level:

Phase:*	1-II	r-II	1-III	r-III	1-IV	r-IV
High, Intermediate	$22,434	$3,451	$22,434	$3,451	$ 863	$ 863
High, Lowest	28,552	4,393	28,552	4,393	1,098	1,098

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*Development phases: 1-II is initial year of Phase II; r-II is remaining years of Phase II, etc.

For the process area, two sources are included in the total costing of Table B-2. Fifty percent (one source) is in this priority category and 50 percent is in the Highest (within sources), and Lowest (between sources) priority level:

Phase:*	1-II	r-II	1-III	r-III	1-IV	r-IV
50-percent costing	$6,994	$1,076	$6,994	$1,076	$ 269	$ 269

For retention basins, costing is from Table B-3:

Phase:*	1-II	r-II	1-III	r-III	1-IV	r-IV
Costing	$4,188	$1,396	$4,188	$1,396	$1,396	$1,396

3. Highest (within), Lowest (between) Priority:

Costing outlined above under items 1 and 2 for waste-chemical characterization.

4. Intermediate (within), Highest (between) Priority:

Product and runoff sampling in process area from Table B-2:

Phase:*	1-II	r-II	1-III	r-III	1-IV	r-IV
Costing	$6,877	$1,672	$6,877	$1,672	$1,672	$1,672

5. Lowest, Intermediate Priority; DOC characterization as follows:

Phase:*	1-II	r-II	1-III	r-III	1-IV	r-IV
Table B-1	$4,680	$4,680	$4,680	$4,680	$4,680	$4,680
Table B-2	864	864	864	864	0	0
Table B-3	288	288	288	288	288	288
	$5,832	$5,832	$5,832	$5,832	$4,968	$4,968

6. Lowest, Lowest Priority; radiological and bacteriological analysis as follows:

Phase:*	1-II	r-II	1-III	r-III	1-IV	r-IV
Table B-1	$3,232	$3,232	$3,232	$3,232	$3,232	$3,232
Table B-2	1,560	1,560	1,560	1,560	0	0
Table B-3	520	520	520	520	520	520
	$5,312	$5,312	$5,312	$5,312	$3,752	$3,752

---

*Development phases: 1-II is initial year of Phase II; r-II is remaining years of Phase II, etc.

Water Use

Assume one survey adequate for the entire tract monitoring program with Intermediate, Lowest Priority.

Hydrogeologic Framework and Water Quality

1. Highest, Highest Priority: Geophysical surveys and test drilling programs in alluvial areas. Assume surveys of Southam Canyon cover needs for both disposal pile and retention-dams source area. Thus geophysical survey costs are $3,400 each for Southam Canyon and process areas, all in initial year Phase II. Test drilling costs (15 holes) listed in Table B-1 are assumed sufficient for entire project area.

2. Highest, Intermediate Priority: Installation, testing, and sampling of new wells:

Phase:*	1-II	r-II	1-III	r-III	1-IV	r-IV
Table B-1	$22,555	$ 0	$19,786	$ 0	$ 0	$ 0
Table B-2	13,684	0	0	0	0	0
	$36,239	$ 0	$19,786	$ 0	$ 0	$ 0

Table B-1 data include retention-dam source area.

3. Highest, Lowest Priority: Identification and characterization of saturated zones above the Bird's Nest Aquifer near the mouth of Southam Canyon and between process area and White River:

Phase:*	1-II	r-II	1-III	r-III	1-IV	r-IV
Table B-1	$41,728	$ 0	$ 0	$ 0	$ 0	$ 0
Table B-2	33,264	0	0	0	0	0

Fracture surveys of Uinta Formation: assumed retention-dam area costs are included in survey costs for processed-shale disposal area. Data for processed-shale disposal area and process area (from Tables B-1 and B-2): $1,600 each area, each phase initial year.

Evaluation of sampling procedures: from Tables B-1 and B-2; costs are $5,370 and $3,035, respectively, in initial year Phase II.

4. Intermediate, Highest Priority: Sampling of existing alluvial valley wells (processed-shale disposal area only):

Phase:*	1-II	r-II	1-III	r-III	1-IV	r-IV
Table B-1	$ 7,776	$5,736	$ 3,469	$3,468	$ 0	$ 0

---

*Development phases: 1-II is initial year of Phase II; r-II is remaining years of Phase II, etc.

5. Lowest, Intermediate Priority:

Test existing Bird's Nest Aquifer wells (processed-shale disposal and process areas):

Phase:*	1-II	r-II	1-III	r-III	1-IV	r-IV
Table B-1	$ 45,000	$ 0	$ 0	$ 0	$ 0	$ 0
Table B-2	30,000	$ 0	0	0	0	0

Install and test new wells (processed-shale disposal area):

Phase:*	1-II	r-II	1-III	r-III	1-IV	r-IV
Table B-1	$112,540	$ 0	$112,540	$ 0	$ 0	$ 0

6. Lowest, Lowest Priority:

New Bird's Nest Aquifer wells in process area: from Table B-2, $75,945 during initial year Phase II.

New Douglas Creek Aquifer wells and testing:

Phase:*	1-II	r-II	1-III	r-III	1-IV	r-IV
Table B-1	$212,280	$ 0	$106,140	$ 0	$ 0	$ 0
Table B-2	137,088	0	0	0	0	0

Infiltration

1. Highest (within sources) Priorities:

Sensor evaluations from Table B-1, $15,862 in initial year of Phase II.

Infiltration in the processed-shale disposal area (Table B-1) is segmented as follows:

- Disposal pile: 85 percent of total
- Southam Canyon alluvium: 5 percent of total
- Uinta Formation: 10 percent of total

Infiltration in the process area (Table B-2) is segmented as follows:

- Tankage and stockpile area: 70 percent of total
- Uinta Formation: 30 percent of total

---

*Development phases: 1-II is initial year in Phase II; r-II is remaining years of Phase II, etc.

Inflitration in retention-dam areas (Table B-3) is segmented as follows:

- Dam and basin areas: 70 percent of total
- Southam Canyon alluvium: 20 percent of total
- Uinta Formation: 10 percent of total

2. Intermediate (within sources) Priorities: Costs for intermediate and lowest (between sources) priorities; split 50-50 from cost in Table B-2 (other process area regions).

Pollutant Mobility

Costing data for pollutant mobility monitoring activities were summed directly from the appropriate segments of Tables B-1, B-2, and B-3, and need not be repeated here. For monitoring of Bird's Nest and Douglas Creek Aquifers, the retention-dams area was considered to be a subset (and thus not an additional cost) of activities for the processed-shale disposal area.

TABLE B-1. MONITORING PROGRAM COSTING DATA--PROCESSED-SHALE PILE SOURCE AREA

Monitoring design step	General activity	Cost items	Cost data	Cost schedule (per year)					
				1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Pollutant-source characterization	Inspection of disposal procedures	Labor	1 day x $160/day - beginning each phase, survey weekly for 6 months, quarterly thereafter (26 days initial years, 4 days remainder years)	$ 4,160	$ 640	$ 4,160	$ 640	$ 4,160	$ 640
		Travel (car)	Assume $25/survey	650	100	650	100	650	100
		Miscellaneous (per diem, film, postage, etc.)	Assume $50/survey	1,300	200	1,300	200	1,300	200
	Waste chemical analyses	General parameters analysis	$14/sample	3,276	504	3,276	504	126	126
		Major inorganics analysis	$75/sample	17,550	2,700	17,550	2,700	675	675
		Trace metals analysis	$85/sample	19,890	3,060	19,890	3,060	765	765
		Organics analysis	$15/sample - Phases II and III: beginning of each phase, collect weekly sample of 9 sources for ∿24 weeks, quarterly thereafter during that phase, annually for Phase IV	3,510	540	3,510	540	135	135
		Sample collection (labor)	1 day/survey at $160	4,160	640	4,160	640	160	160
		Other equipment rental (truck, pump, etc.)	Assume $100/day	2,600	400	2,600	400	100	100
	Waste chemical analyses	DOC fractionation	$130/sample, quarterly	4,680	4,680	4,680	4,680	1,170	1,170
		Radiological parameters analysis	$55/sample, quarterly	1,980	1,980	1,980	1,980	495	495
		Bacteriological parameters analysis	$17/sample, quarterly	612	612	612	612	153	153

(continued)

TABLE B-1 (continued)

Monitoring design step	General activity	Cost items	Cost data	Cost schedule (per year)					
				1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Pollutant-source characterization (continued)	Waste chemical analyses (continued)	Sample collection	Assume quarterly samples from 9 sources for Phases II and III, annually for Phase IV	$ 640	$ 640	$ 640	$ 640	$ 640	$ 640
			1 day/survey at $160						
Water use	Review available documents on area development and water use	Labor	1 week/year x $160/day	800	800	800	800	800	800
Hydrogeologic framework and existing water quality	Alluvium characterization:								
	Geophysical surveys	Survey team	Assume 1 week at $85/hour	3,400	0	0	0	0	0
	Test drilling	15 test holes	Hole drilling plus 1 week at $85/hour	8,125	0	0	0	0	0
	Install new wells	Phase II: 9 wells total; 6 with 6-inch diameter casing, 3 with 8-inch diameter casing	6-inch wells at $837 and 8-inch wells at $1,053	8,181	0	7,128	0	0	0
		Phases III and IV: 8 wells total; 6 with 6-inch diameter casing, 2 with 8-inch diameter casing							
	Test new wells	Phase II: 3 tests	Phase II, each test: 24 hours x $40/hour	2,880	0	1,920	0	0	0
		Phases III and IV: 2 tests	Phases III and IV, each test: 24 hours x $40/hour						
	Sample new wells (partially associated with pollutant mobility monitoring)	Quarterly analysis (listed under pollutant-source characterization)	$189/sample. Phase II: 9 wells each quarter Phases III and IV: 8 wells each quarter	6,804	0	6,804	0	0	0

(continued)

TABLE B-1 (continued)

Monitoring design step	General activity	Cost items	Cost data	Cost schedule (per year) 1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Hydrogeologic framework and existing water quality (continued)	Alluvium characterization: (continued)								
	Sample new wells (continued)	Other equipment rental (truck, submersible pump, generator, field instruments) for sampling	Assumed $110/day at 2 days/ quarter	$ 880	$ 0	$ 880	$ 0	$ 0	$ 0
		Labor (for sampling)	4 man days/quarter at $160/day	2,560	0	2,560	0	0	0
	Uinta Formation and Green River Formation characterization:								
	Geologic mapping	Field surveys of areas cleared down to Uinta Formation surface	Assume 2 man weeks during initial year of each phase at $160/day	1,600	0	1,600	0	1,600	0
	Identify and characterize saturated zones near mouth of Southam Canyon	Test drilling	3 test holes -drilling -logging	24,156 3,525	0 0	0 0	0 0	0 0	0 0
		Well installation 8-inch - 1 6-inch - 1	$7,343 4,204	11,547	0	0	0	0	0
		Testing	5 days at $500/day	2,500	0	0	0	0	0
	Bird's Nest Aquifer characterization:	Evaluate sampling methods (possibility of pumping to sample; compare pumped to bailed samples)	Assume 2 man weeks during initial operational year at $160/day	1,600	0	0	0	0	0
			Sample analysis (general parameters and major inorganic constituents) at $89/sample; assume 30 samples total	2,670	0	0	0	0	0
			Field instrument rental and supplies at $10/day	100	0	0	0	0	0

(continued)

TABLE B-1 (continued)

Monitoring design step	General activity	Cost items	Cost data	Cost schedule (per year)					
				1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Hydrogeologic framework and existing water quality (continued)	Bird's Nest Aquifer characterization: (continued)	Other equipment rental (truck, submersible pump, generator)	Assumed to be $100/day	$ 1,000	$ 0	$ 0	$ 0	$ 0	$ 0
	Alluvium characterization:								
	Sample alluvial water quality at existing wells (6 wells)	Monthly field (pH, EC, DO) surveys	1 day/month at $160/day plus $10/day equipment rental and expendable supplies	2,040	0	0	0	0	0
		Quarterly analyses (listed under pollutant-source characterization)	Phase II: $189/sample x 6 wells x 4 quarters. 3 wells during Phase III	4,536	4,536	2,268	2,268	0	0
		Other equipment rental (truck, submersible pump, generator)	Assumed to be $100/day	1,200	1,200	1,200	1,200	0	0
	Determine flow patterns	Labor (office)	1 man week at $250/day	1,200	0	1,250	0	0	0
	Bird's Nest Aquifer:								
	Test existing wells	Assume 3 tests of 30-day duration	30 days at $500/day x 3 days	45,000	0	0	0	0	0
	Install new wells	Assume 4 wells (2 with 6-inch diameter casing, 2 with 8-inch diameter casing) at initiation of both Phase II and Phase III	6-inch wells at $18,293 8-inch wells at $22,977	82,540	0	82,540	0	0	0
	Test new wells	Assume 2 tests each for Phase II and Phase III (8-inch wells tested)	30 days average at $500/day x 2 tests	30,000	0	30,000	0	0	0

(continued)

TABLE B-1 (continued)

				Cost schedule (per year)					
Monitoring design step	General activity	Cost items	Cost data	1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Hydrogeologic framework and existing water quality (continued)	Douglas Creek Aquifer characterization:								
	Install new wells	Phase II: 4 new wells (2 with 6-inch and 2 with 8-inch diameter casing)	6-inch wells at $37,596 8-inch wells at $47,544	$170,280	$ 0	$ 85,140	$ 0	$ 0	$ 0
		Phases III and IV: 2 new wells (1 with 6-inch and 1 with 8-inch diameter casing)							
	Test new wells	Test 8-inch wells	30 days at $400/day average	42,000	0	21,000	0	0	0
Infiltration	Infiltrometer tests	Labor: assume 10 tests during each of 4 aspects of pile development for Phase II, and a similar series for start of Phase III. Assume 0.5 man days/test	Phase II: 40 tests at 0.5/day at $160/day Phase III: same	3,200	0	3,200	0	0	0
	Sensor evaluations	Access holes for neutron logging	10 sites x 1 access hole at 20-foot depth; augering $45/hour x 0.5/hour hole; casing $5/foot	1,225	0	0	0	0	0
		Neutron logger	Well Reconnaissance, Inc.	10,835	0	0	0	0	0
		Tensiometers	$70.50/site (3/site)	705	0	0	0	0	0
		Suction cup lysimeters	$29.50/each (3/site)	885	0	0	0	0	0
		Moisture blocks	$3.80/site (3/site)	38	0	0	0	0	0
		Soil moisture meter	$149	149	0	0	0	0	0

(continued)

TABLE B-1 (continued)

Monitoring design step	General activity	Cost items	Cost data	Cost schedule (per year)					
				1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Infiltration (continued)	Sensor evaluations (continued)	Salinity sensors	$41/each (3/site)	$ 1,230	$ 0	$ 0	$ 0	$ 0	$ 0
		Salinity bridge	$795	795	0	0	0	0	0
Pollutant mobility	Monitoring in the processed-shale pile	Maintain infiltration test plots	Assume 10 Phase II and 10 Phase III are permanent: sample monthly 1st year, quarterly thereafter						
		-Monitor water content (neutron logging, tensiometers, moisture blocks)	Assume 2 man days/survey at at $160/day						
			Phase II:	3,840	1,280	1,280	1,280	1,280	1,280
		-Monitor pollutant mobility	Phase III:	0	0	3,480	1,280	1,280	1,280
		Monitor beneath revegetation trenches - assume 5 sites, Phase II; 10 sites, Phase III; 10 sites, Phase IV; established probably after 1st year							
		-Installations:							
		Access holes	$200/each	1,000	0	2,000	0	2,000	0
		Tensiometers	$70.50/each/site	353	0	705	0	705	0
		Suction cup lysimeter sets	$88.50/each/site	443	0	885	0	885	0
		Moisture block sets	$3.80/each/site	19	0	38	0	38	0
		Salinity sensor sets	$123/each/site	615	0	1,230	0	1,230	0
		-Monitoring surveys, quarterly	Phase II - 5 sites Phase III - 15 sites Phase IV - 25 sites	160	160	480	480	800	800

(continued)

TABLE B-1 (continued)

Monitoring design step	General activity	Cost items	Cost data	Cost schedule (per year) 1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Pollutant mobility (continued)	Monitoring in the processed-shale pile (continued)	-Monitoring surveys, quarterly (continued)	5 sites/day at $160/day (labor)						
		Sample analysis	Assume 10 samples/quarter, Phase II; 20 for Phase III; 20 for Phase IV	$ 7,560	$ 7,560	$ 15,120	$ 15,120	$ 15,120	$ 15,120
			$189/sample						
	Monitoring in the alluvium	Surface resistivity surveys	Annual surveys: assume 8 hours at $80/hour plus 2 man days travel at $160/day	640	640	640	640	640	640
				320	320	320	320	320	320
		Monitor wells Phase II: 6 existing wells, 9 new wells	Quarterly, $189/sample (initial year considered above under Hydrogeologic Framework)	0	11,340	0	8,316	2,079	2,079
		Phases III and IV: 3 existing wells; 8 new wells	Annual survey, Phase IV, assumed						
		(Installation considered under Hydrogeologic Framework)							
	Monitoring in the Uinta Formation and Green River Formation above Bird's Nest Aquifer	Locate and install access holes according to fracture survey results	Assume $1,000/hole, 4 access holes for Phase II, 8 for Phases III and IV	4,000	0	4,000	0	4,000	0
		Neutron logging	Assume quarterly surveys, 1 day for each set of 4 access holes at $160/day	0	160	160	320	320	480
		Sample 2 wells	Quarterly surveys initial year, annual thereafter	1,512	378	378	378	378	378
			$189/sample						

(continued)

TABLE B-1 (continued)

Monitoring design step	General activity	Cost items	Cost data	Cost schedule (per year)					
				1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Pollutant mobility (continued)	Monitoring in the Bird's Nest Aquifer	Phase II: sample 2 existing and 4 new wells (see Hydrogeologic Framework for well installation)	Phase II: quarterly surveys for initial year (new wells), annually thereafter $189/sample	$ 3,402	$ 1,134	$ 0	$ 0	$ 0	$ 0
		Phases III and IV: sample Phase II wells (6), 3 existing wells, and 4 new wells (see Hydrogeologic Framework for well installation)	Phases III and IV: quarterly surveys for initial year (new wells), annually thereafter $189/sample	0	0	4,725	2,457	2,457	2,457
		Miscellaneous equipment rental	$100/day, 2 wells/day	900	300	1,250	650	650	650
	Monitoring in the Douglas Creek Aquifer	Phase II: sample 4 new wells (see Hydrogeologic Framework for well installation)	Annual surveys, $189/sample	756	756	1,134	1,134	1,134	1,134
		Phases III and IV: sample Phase II plus 2 new wells							
		Miscellaneous equipment rental	$100/day, 1 well/day	400	400	600	600	600	600

TABLE B-2. MONITORING PROGRAM COSTING DATA--PROCESS AREA

				Cost schedule (per year)					
Monitoring design step	General activity	Cost items	Cost data	1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Pollutant-source characterization	Surveys of development and construction activities	Labor: 1 day/survey. Survey weekly for 6 months and quarterly thereafter for each phase of development.	$160/day labor	$ 4,160	$ 640	$ 4,160	$ 640	$ 4,160	$ 640
		Travel and miscellaneous expenses (film, photocopy, etc.)	Assume $75/survey	1,950	300	1,950	300	1,950	300
	Waste chemical analyses -Waste water holding pond -Raw shale	Analysis for general parameters, major inorganics, trace metals, and organics Phases II and III: initially collect weekly samples for ~24 weeks, quarterly thereafter. Annual sampling during Phase IV.	$189/sample	9,828	1,512	9,828	1,512	378	378
		Sample collection	1 day/survey at $160	4,160	640	4,160	640	160	160
	Waste chemical analyses -Miscellaneous products -Runoff -Soils stockpiles	Analysis for general parameters, major inorganics, trace metals, and organics Assume equivalent of 8 sources sampled quarterly initially, then annually. 1 soil survey (in Phase II)	$189/sample	6,237	1,512	6,048	1,512	1,512	1,512
		Sample collection	1 day/survey at $160	640	160	640	160	160	160

(continued)

TABLE B-2 (continued)

Monitoring design step	General activity	Cost items	Cost data	Cost schedule (per year) 1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Pollutant-source characterization (continued)	Waste chemical analyses -Water storage basin -Treatment plant	Analysis for general parameters, major inorganics, trace metals, and organics Assume quarterly sampling initially during Phases II and III, then annually	$189/sample	$ 1,512	$ 378	$ 1,512	$ 378	$ 378	$ 378
		Sample collection	1 day/survey at $160	640	160	640	160	160	160
	Waste chemical analyses -All potential sources above	DOC fractionation, radiological and bacteriological analysis. Assume annual sampling at equivalent of 12 sources (Phases II and III only)	$202/sample	2,424	2,424	2,424	2,424	0	0
		Sample collection	1 day/survey at $160	160	160	160	160	0	0
Water use	Review available documents on area development and water use	Labor	1 week/year at $160/day	800	800	800	800	800	800
Hydrogeologic framework and water quality	Alluvium characterization:								
	Geophysical surveys	Survey team	Assume 1 week at $85/hour	3,400	0	0	0	0	0
	Install new wells	Assume 8 wells total: 5 with 6-inch casing, 3 with 8-inch casing	6-inch wells at $478 and 8-inch wells at $602	4,196	0	0	0	0	0
	Sample new wells	Quarterly sampling for general parameters, major inorganics, trace metals, and organics	$189/sample	6,048	0	0	0	0	0

(continued)

TABLE B-2 (continued)

Monitoring design step	General activity	Cost items	Cost data	Cost schedule (per year) 1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Hydrogeologic framework and water quality (continued)	Alluvium characterization: (continued)								
	Sample new wells (continued)	Phase II initial year only. Other monitoring under Pollutant Mobility step.							
		Equipment for sampling	Assume $110/day and 2 days/ quarter	$ 880	$ 0	$ 0	$ 0	$ 0	$ 0
		Labor	Assume 4 man days/quarter at $160/day	2,550	0	0	0	0	0
	Uinta Formation and Green River Formation characterization:								
	Geologic mapping	Field surveys of cleared areas	Assume 2 man weeks during initial year of each phase at $160/day	1,600	0	1,600	0	1,600	0
	Identify and characterize saturated zones between process area and White River	Test drilling	2 test holes						
			-drilling	16,855	0	0	0	0	0
			-logging	2,362	0	0	0	0	0
		Well installation 6-inch - 1 8-inch - 1	 $7,343 4,204	11,547	0	0	0	0	0
		Testing	5 days at $500/day	2,500	0	0	0	0	0
	Bird's Nest Aquifer characterization:	Evaluate sampling methods	Labor: 2 man weeks during initial year at $160/day	1,600	0	0	0	0	0
			Sample analysis: 15 samples at $89	1,335	0	0	0	0	0
		Equipment for sampling	$110/day for 10 days	1,100	0	0	0	0	0

(continued)

TABLE B-2 (continued)

Monitoring design step	General activity	Cost items	Cost data	Cost schedule (per year) 1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Hydrogeologic framework and water quality (continued)	Alluvium characterization:								
	Test new wells	3 tests on 8-inch wells	24 hours/test at $40/hour	$ 2,880	$ 0	$ 0	$ 0	$ 0	$ 0
	Determine flow patterns	Labor (office)	1 man week at $250/day	1,250	0	0	0	0	0
	Bird's Nest Aquifer characterization:								
	Test existing wells	Assume 2 tests of 30-day duration	30 days at $500/day on each test	30,000	0	0	0	0	0
	Install new wells	Assume two 8-inch wells	8-inch wells at $22,977 each	45,954	0	0	0	0	0
	Test new wells	2 tests of 30-day duration	30 days at $500/day on each test	30,000	0	0	0	0	0
	Douglas Creek Aquifer characterization:								
	Install new wells	Assume two 8-inch wells	8-inch wells at $47,544 each	95,088	0	0	0	0	0
	Test new wells	2 tests of 30-day duration	30 days at $700/day on each test	42,000	0	0	0	0	0
Infiltration	Infiltrometer tests:								
	In holding pond, tankage, and stockpile areas	Assume 12 test sites for initial year of Phases II and III	Each of 2 phases: 12 tests at 0.5/day each at $160/day	960	0	960	0	0	0
	In other portions of the process area	Assume 12 test sites	Each of 2 phases: 12 tests at 0.5/day each at $160/day	960	0	960	0	0	0

(continued)

TABLE B-2 (continued)

Monitoring design step	General activity	Cost items	Cost data	Cost schedule (per year)					
				1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Pollutant mobility	Monitoring in the alluvium	Surface resistivity surveys	Annual surveys: assume 8 hours at $80/hour plus 2 man days travel at $160/day	$ 960	$ 960	$ 960	$ 960	$ 960	$ 960
		Sample monitor wells (8 new wells							
		-Monthly sampling of pH, EC, Eh	2 days/month at $160/day	3,840	3,840	3,840	3,840	3,840	3,840
		-Quarterly sampling	$189/sample	6,048	6,048	6,048	6,048	6,048	6,048
		Install tensiometers	24 arrays of 3 tensiometers each at $70.50 each	1,692	0	0	0	0	0
		Monitor tensiometers monthly	2 man days/month at $160/day	3,840	3,840	3,840	3,840	3,840	3,840
		Install suction cup lysimeters	24 arrays of 3 lysimeters each at $88.50/site	2,124	0	0	0	0	0
		Quarterly surveys	Assume ~5 arrays/day at $160/day	800	800	800	800	800	800
		Sample analysis	Assume 10 samples/quarter at $189/sample	7,560	7,560	7,560	7,560	7,560	7,560
	Monitoring in the Uinta Formation	Locate and install access holes according to geologic survey results	Assume $1,000/hole, 8 access holes; 4 during Phase II, 4 during Phase III	4,000	0	4,000	0	0	0
		Neutron logging	Assume quarterly surveys 1 day for each 4 access holes at $160/day	640	640	1,280	1,280	1,280	1,280
	Monitoring in the Green River Formation above Bird's Nest Aquifer	Sample 2 wells	Quarterly surveys initial year, annually thereafter $189/sample	1,512	378	378	378	378	378

(continued)

TABLE B-2 (continued)

				Cost schedule (per year)					
Monitoring design step	General activity	Cost items	Cost data	1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Pollutant mobility (continued)	Monitoring in the Bird's Nest Aquifer	Sampling in 3 existing and 2 new wells	Quarterly for initial year for new wells; annual surveys otherwise $189/sample	$ 2,079	$ 945	$ 945	$ 945	$ 945	$ 945
		Miscellaneous equipment rental	Assume $100/day and 2 wells/day	600	300	300	300	300	300
	Monitoring in the Douglas Creek Aquifer	Sampling in 2 new wells	Annual surveys $189/sample	378	378	378	378	378	378
		Miscellaneous equipment rental	$100/day and 1 well/day	200	200	200	200	200	200

TABLE B-3. MONITORING PROGRAM COSTING DATA--RETENTION DAMS

Monitoring design step	General activity	Cost items	Cost data	Cost schedule (per year) 1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Pollutant-source characterization	Surveys of development and construction activities	For initial years of Phases II and III, 1 day/week during clearing and construction	Assume 1 day/week, 24 weeks at $160/day	$ 3,840	$ 0	$ 3,840	$ 0	$ 0	$ 0
	Retention basin water characterization	Analysis of samples for general parameters, major inorganics, trace metals, and organics (DOC)	Assume equivalent of monthly sampling for initial year Phases II and III, quarterly thereafter, and during Phase IV $189/sample	2,268	756	2,268	756	756	756
		Sample collection	1 day/survey at $160/day	1,920	640	1,920	640	640	640
	Retention basin water characterization	Analysis of samples for DOC fractionation, radiological, and bacteriological constituents	$202/sample. Assume quarterly sampling.	808	808	808	808	808	808
Water use	Review available documents on area development and water use	Labor	1 week/year at $160/day	800	800	800	800	800	800
Hydrogeologic framework and water quality[a]	Alluvium characterization:			34,080	0	19,786	0	0	0
	-Geophysical surveys								
	-Test drilling								
	-Install, test, sample new wells	See Table B-1 for costing detail							
	-Determine flow patterns								
	Uinta Formation and Green River Formation characterization:			43,328	0	1,600	0	0	0

(continued)

TABLE B-3 (continued)

Monitoring design step	General activity	Cost items	Cost data	Cost schedule (per year) 1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Hydrogeologic framework and water quality[a] (continued)	Uinta Formation and Green River Formation characterization: (continued)								
	-Geologic mapping								
	-Identify and characterize saturated zones			$ 5,370	$ 0	$ 0	$ 0	$ 0	$ 0
	Bird's Nest Aquifer characterization:								
	-Evaluate sampling methods			7,776	5,736	3,468	3,468	0	0
	Alluvium characterization:								
	-Sample existing wells	See Table B-1 for costing detail		369,820	0	218,680	0	0	0
	Bird's Nest and Douglas Creek Aquifer characterization								
Infiltration	Infiltrometer tests	Assume 12 test sites for initial year of Phases II and III	Each of 2 phases: 12 tests at 0.5/day each at $160/day	960	0	960	0	0	0
Pollutant mobility	Monitoring within and beneath retention dams	Install access holes	Assume 6 holes at $1,000 for each retention dam	6,000	0	6,000	0	0	0
		Neutron logging	Assume same schedule as retention basin water sampling, 1 day/survey at $160/day	1,920	640	1,920	640	640	640

(continued)

TABLE B-3 (continued)

Monitoring design step	General activity	Cost items	Cost data	Cost schedule (per year) 1st year Phase II	Remainder Phase II	1st year Phase III	Remainder Phase III	1st year Phase IV	Remainder Phase IV
Pollutant mobility (continued)	Monitoring within and beneath retention dams (continued)	Other installations:							
		-Tensiometers	6 arrays/dam at $70.50 each	$ 423	$ 0	$ 423	$ 0	$ 0	$ 0
		-Suction-cup lysimeters	6 arrays/dam at $29.50 each	177	0	177	0	0	0
		Sample analysis	Assume 25 samples/year at $189/sample	4,725	4,725	4,725	4,725	4,725	4,725
	Monitoring in the alluvium	Surface resistivity surveys	Annual surveys assume 8 hours at $80/hour plus 2 man days travel at $160/day	960	960	960	960	960	960
		Monitor wells:							
		-Phase II, 4 wells	Assume quarterly sampling during Phases II and III and annual surveys during Phase IV at $189/sample	3,024	3,024	3,024	3,024	3,024	3,024
		-Phases III and IV, 4 wells							
	Monitoring in the Uinta Formation and Green River Formation above Bird's Nest Aquifer	Locate and install access holes according to geologic survey results	Assume $1,000/hole; 4 access holes for Phase II site and 4 for Phases III and IV sites	4,000	0	4,000	0	0	0
		Neutron logging	Assume quarterly surveys, 1 day for each access hole	640	640	640	640	640	640
		Sample 2 wells	See Table B-1	1,512	378	378	378	378	378
	Monitoring in deep aquifers	See Table B-1 for costing detail		5,458	2,590	7,709	4,841	4,841	4,841

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[a] The cost data presented here are a repeated listing of cost estimates presented in Table B-1 for the processed-shale disposal area. Requirements for the retention dams are a subset of requirements for the disposal area.

APPENDIX C

REPORT ON PROCESSED-SHALE LEACHATE STUDIES

COLUMN EXPERIMENTS

As part of the assessments of monitoring requirements for processed-shale disposal, a set of simple column experiments was performed. Processed shale from the Paraho indirect retorting process was used. Columns of processed shale obtained from the Anvil Points experimental site were moistened to a level of 10 percent by weight with various waters associated with retorting operations or with deionized water (Table C-1). The columns were then leached, under constant head conditions, with deionized water. The purpose of these experiments was to assess capabilities for differentiating among the materials that might contribute to leachate from processed-shale piles. Some information on pollutant attenuation mechanisms can also be gained from such experiments. These experiments were reconnaissance in nature since expected field conditions were not simulated.

Although saturated flow conditions are clearly unrealistic with regard to conditions generally expected in surface processed-shale disposal piles, some inferences can be made from examination of discharge vs. time data (Figure C-1). Similar patterns were observed for experimental columns 1, 2, and 4, with initial, relatively high, discharge rates followed by slight decreases and a gradual increase toward the end of the experiments. The initial decrease may be due to compaction within the columns and the gradual increase may be due to the effect of increased pore size from dissolution of soluble materials. However, it should be noted that the discharges (Figure C-1) were highly variable and the results not conclusive.

The discharge from experimental column 3 initially reached levels comparable to column 1, but rapidly and continually decreased after the initial few hours of the experiment (Figure C-1). This decrease may be explained by plugging of pores with colloidal material from the simulated landfill leachate or deposition of precipitates, such as iron hydroxide [$Fe(OH)_2$]. As will be noted below (Figure C-2), this decreasing discharge period is associated with the observed breakthrough of the simulated landfill leachate in the column 3 discharge. The discharge from column 5 was fairly constant after the initial peak (Figure C-1) and was probably controlled by the lower permeability of the soil columns.

The results of chemical analysis of discharges from the experimental columns are summarized in the following discussion. The data are presented in Figures C-3 through C-18, located at the end of this appendix.

INORGANIC CHEMICAL ANALYSIS

Major Inorganic Ions

Analysis of chloride and sulfate levels in column discharges showed the general patterns displayed for the electrical conductivity data (Figure C-1). From initial high levels, concentrations decreased by about 80 to 90 percent with the first 1,000 milliliters of discharge from all columns. The levels of these anions showed a secondary peak for column 3 as a result of the breakthrough of the simulated landfill leachate.

In experimental columns 1 through 4, fluoride concentrations decreased from initial levels of 15 to 20 milligrams per liter to about 10 to 12 milligrams per liter at the end of the experiment. Thus, the mobility of fluoride within processed-shale piles would appear to be appreciable. Observed levels in column 5 (containing both processed shale and soil layers) were always less than 1 milligram per liter. Fluoride in processed-shale leachate was probably precipitated as fluorite (CaF_2) as a result of interaction with calcic soil materials.

Analysis of major cations (Na, K, Ca, Mg) shows the effect of ion exchange between the processed-shale leachate and the soil column. The observed concentrations of these constituents in experimental columns 1 through 4 are very similar. However, column 5 shows initially high (relative to the other columns) levels of magnesium and calcium and initially lower levels of sodium and potassium. The likely mechanism in the soil column is an exchange of calcium and sodium in the soil matrix for sodium and to a much smaller extent for potassium. With such an exchange, sodium and potassium are diminished in the final column leachate, and calcium and magnesium are increased.

However, the difference in cation levels between processed-shale (column 4) leachate and shale-soil (column 5) leachate cannot be explained completely by Na-K to Ca-Mg exchanges. The increase in calcium and magnesium accounts for less than 50 percent of the decrease in sodium and potassium. The additional potential processes include:

- The precipitation of $CaCO_3$ and $MgCO_3$ after Ca-Mg to Na exchange process (this would aid explanation of decreased conductivity of column 5 vs. column 4 leachate and low pH (~7) of column 5 leachate relative to the other columns (with pH over 12)
- The exchange of Na in processed-shale leachate for hydrogen ions on soil exchange sites (this would decrease pH but not conductivity)
- Precipitation of gypsum ($CaSO_4$), which may be supported by observed difference in sulfate levels (~100 milligrams per liter initially) between columns 4 and 5.

These latter mechanisms may explain the substantial decline in calcium concentrations observed after the initial samples discussed above. Although the nature of the processes is unclear, it would appear that movement of processed-shale leachate through underlying soils may provide appreciable attenuation of potential pollutants. This would, of course, depend upon the characteristics of the underlying soils.

Trace Elements

Analysis of constituents in experimental column effluents included arsenic, barium, chromium, copper, iron, lead, nickel, selenium, strontium, and zinc determinations. All observations of arsenic were less than 1 milligram per milliliter. Hence, it would appear that although relatively high arsenic levels exist in process and product waters (measured at 10.3 and 22.2 milligrams per milliliter, respectively), arsenic was not mobile in the processed-shale columns. It should be noted that the analytical method used during these feasibility experiments was not very sensitive. In addition, the source of the oil shale plays an uncertain role in determining the results observed.

Similarly, low levels of chromium (usually less than 0.03 milligram per milliliter), iron (usually less than 0.2 milligram per milliliter), and lead (less than 0.10 milligram per milliliter) were observed in processed-shale leachate. A column 3 maximum of 0.05 milligram per milliliter chromium may be due to some enhanced mobility by the acidic simulated landfill leachate (pH = 6.3). Precipitation as hydroxides is the likely attenuation mechanism for iron. Peak lead levels of 0.19 and 0.23 milligram per milliliter for leachates of columns 2 and 3, respectively, may be due to mobility of lead in product (0.40 milligram per milliliter) and process (0.15 milligram per milliliter) waters.

Barium concentrations in column effluents were a fairly constant 0.5 to 0.7 milligram per liter throughout the experiments, indicating moderate solubility. Because similar levels were observed for columns with and without product, process, or pond water moistening, the major source of barium is the processed shale. The soil is also indicated to be a potential source of barium.

The processed shale is also indicated to be the major source of copper, nickel, strontium, and probably zinc in column leachate. The soil column also provided significant amounts of copper, selenium, and strontium. The simulated landfill leachate may also have enhanced the mobility of nickel, selenium, and strontium. The pond, process, and product waters also appear to contribute to selenium levels in column leachate.

ORGANIC CHEMICAL ANALYSIS

Accompanying the column experiments described previously, a set of experiments was also performed to assess potential organic interactions in processed-shale disposal piles. In these "shaker" tests, various masses of processed shale (from the same source used for column tests) were placed in flasks with 30 milliliters of various liquids (Table C-2). The stoppered flasks were than shaken for 48 hours and the samples filtered first through glass wool and then through a 0.45 micron silver impregnated membrane filter. Samples were then analyzed for six fractions of dissolved organic carbon as listed in Table C-2. The major purpose of these experiments was to obtain some preliminary data on the differential character and adsorption of various oil shale waste waters.

The results of these shaker tests are plotted in Figures C-19 through C-21. Observations made from these plots and from the data in Table C-2 are as follows:

- The organics in process and product waters (see Table C-1) were of very similar general compositions although the process water had somewhat greater proportions of hydrophobic acids and lesser proportions of hydrophilic acids.

- For both process and product waters, interaction with processed shale reduced total DOC levels appreciably, indicating significant sorption, but the relative amounts of the various organic fractions remained fairly constant.

- Pond water (see Table C-1) exhibited lower DOC levels than either process or product waters. The levels observed for the pond were similar to those observed for the processed-shale/deionized water shaker tests.

- The composition of the pond water was also different from process and product waters, showing relatively elevated levels of both hydrophobic and hydrophilic neutral fractions and low hydrophobic acid levels.

- With regard particularly to the hydrophobic acid and neutral fractions, the deionized water-processed shale results were quite variable, although the total DOC levels were similar for the two samples.

- The somewhat elevated hydrophobic neutral fraction in pond water may show the influence of processed-shale leachate; one of the processed-shale (deionized water) leachate samples showed similar peak in this fraction.

- The composition of the hydrophilic fraction of the pond water is appreciably different from that observed for the processed-shale leachate. The leachate hydrophilic fraction is more similar to that observed for process and product waters with an overwhelming dominance of the acid component.

- The total DOC of the pond water was increased by interaction with the processed shale, indicating the dominance of organic leaching processes (particularly of the hydrophobic acid and hydrophilic acid and neutral fractions) over sorption processes.

MONITORING THE PROCESSED-SHALE PILE

One of the interesting problems that presented itself during the monitoring design study was the nature of the spent-shale disposal pile. Analysis was initiated with consideration of over a dozen individual solid and liquid waste sources. However, ultimately, most of these materials may be conglomerated in the spent-shale disposal area. Solid wastes are deposited with the spent shale, and liquid wastes are used in dust control and compaction efforts. Thus, rather than having a dozen or so individual sources to monitor, we have one combined source.

The question then arises, if we sample (or monitor) waters running off of or leaching through the processed-shale pile, do the solute materials come from spent shale, raw shale, retort or other process water, or where? The question of original or ultimate source may arise because, for environmental control, it may be more cost-effective to address an individual source (e.g., via pretreatment, special handling, etc.) than to address the entire source area (e.g., via diversions, drainage control, etc.). Hence, it seems advantageous to be able to interpret data collected to identify the original individual source of the solutes collected.

Identification or separation of the sources of materials leaching from a spent-shale pile will have to depend on differences in composition and concentration of the individual constituents. Two major methods of separating the sources are available (Phillips, 1977). The first is differences in concentration of the major ions, and the second is identification of "tracer" constituents peculiar to individual pollution sources. The advantage of the first method is that it may require only standard chemical analyses of the collected water: the commonly analyzed major inorganic constituents are calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, and sulfate. If the results of these analyses are given as equivalents per liter, the concentration of individual cations and anions can be divided by the total anion or cation concentrations to give percentages. These percentages can then be plotted on a trilinear diagram (Figure C-22). An advantage of the trilinear diagram is that mixtures of two waters of differing composition will plot on a straight line between the positions of the two different waters. Thus it is possible to estimate the contribution of various pollution sources if their individual compositions are known.

The data plotted on Figure C-22 represent reported chemical analyses of retort waters, raw-shale leachate, and processed-shale leachate from various retorting processes. The trilinear plot of these data shows that these three types of sources may be distinguishable from differences in their inorganic ion compositions. This differentiation is most clearly shown in the anion field, where the four processed-shale leachate samples plot in one area, raw-shale leachate in another, and the two retort water samples in a third region.

Although some feasibility for source differentiation has been shown in these data, additional work is obviously required to formalize the monitoring procedure. In addition, the major ion comparison is probably insufficient by itself to distinguish between the various pollutant sources (Phillips, 1977). More complete knowledge of source-chemical characteristics and the mobility of these constituents in the subsurface may identify "tracer" chemical species to support the monitoring program.

Figure C-23 shows the plot of some of the data collected during the column experiments described earlier. The initial leachate samples from processed-shale columns moistened with retention-pond water (sample 1a) and with deionized water (sample 4a) were sodium sulfate waters, which characterize processed-shale leachate. Columns moistened with product and process waters produced leachates (samples 2a and 3a) with a sodium-sulfate-chloride composition (Figure C-23). The plot location of sample 5a shows the appreciable influence of leachates moving through a soil column.

Sampling programs that include general fractionation procedures would offer some information on the types of organics that are mobile in the hydrosphere. With this approach, the general character of the organic complex would be identified (e.g., dominance of hydrophobics or hydrophilic acids, etc.), and hence "candidate compound types" could be inferred through the use of information on more detailed source characterization.

Some data have been presented (Stuber and Leenheer, 1978) that indicate that certain organic fractions of oil shale retort waters are differentially sorbed on spent shale (Figure C-24). Also, the organic composition of organic waste sources may be sufficiently different (Table C-2) to allow differential detection of the ultimate pollutant source in the spent-shale disposal area. The concept of differential detection was presented earlier in the discussion of inorganic sampling.

The interpretive utility of fractionation data would be greatly enhanced if the potential toxicity, carcinogenicity, etc. were nonuniformly distributed among the various general organic fractions. For example, if hydrophobic bases were extremely carcinogenic relative to hydrophobic acids, then an observation of the increasing dominance of the former fraction would offer more information than if no such toxicological difference existed. Some research is presently underway to address the potential biological effects of various organic fractions of oil shale wastes. This type of information will clearly enhance the potential utility of fractionation schemes for monitoring. However, the extent to which these data on differential fraction toxicity are process-dependent must also be assessed.

The results of the column experiments presented earlier indicated some potential for differentiation of various original sources using the six-way DOC fractionation method. However, these few experiments are insufficient to formulate a recommended monitoring approach for data analysis and interpretation.

Designating the chemical sampling and analysis components of a water quality monitoring program calls for the assessment of analytical capabilities, operation costs, and the potential use or utility of the data collected. Numerous analytical procedures are available for use in the monitoring of oil shale development. Analytical alternatives range from very general measures to specific elements and compounds. The interpretive utility of the results of alternative analytical procedures varies widely as do the costs of monitoring.

Inorganic chemical sampling needs for monitoring oil shale operations have been identified using a stepwise design methodology developed by GE-TEMPO. Analytical procedures are considered standard (although some questions have been raised on this issue), costs are moderate and, in general, criteria for data interpretation exist.

Organic chemical sampling needs are less well defined. Of the four general organic analysis categories (gross organic measures, general fractionation, more specific fractionation, and specific compound analysis), none alone appears at this time to be clearly superior with regard to ease of data collection and utility of data for environmental interpretation.

The best approach may thus be a "sequential" monitoring procedure. In such a program, a basic monitoring effort includes measurement of rather general organic parameters (e.g., COD or TOC). Appreciable changes in these parameters would indicate the need for further sampling and analysis using more sophisticated chemical analysis approaches to more clearly define the nature of the change.

In addition, the inclusion of such more detailed (and more readily interpretable and generally more expensive) sampling and analysis on a regular basis, but less frequently than the basic program, may be advantageous. This would allow detection of changes in organic composition when the measured "level" of organics is relatively constant. Direct biological measures of potential environmental hazard may also be a useful component of these efforts, enhancing the interpretive capability of the monitoring program.

TABLE C-1. EXPERIMENTAL DESIGN FOR FLOW AND LEACHATE TESTS

Column experimental number:	1	2	3	4	5
Mass (gm) of processed shale	1,229	1,249	1,229	1,219	1,230[a]
Dry bulk density (gm/cm^3)	1.134	1.120	1.134	1.095	1.042
Porosity (percent)	55.5	55.3	57.5	52.8	53.5
Moistening agent(s)	Pond water[b]	Diluted process plus product water[c]	Diluted process plus product water[c,d]	Deionized water	Deionized water
Flow state	Saturated	Saturated	Saturated	Saturated	Saturated
Head above column (inches)	2.0	2.0	2.0	2.0	2.0
Vertical saturated hydraulic conductivity (m/d)	0.78	0.90	0.09	1.10	0.22

[a] Column of processed shale packed over 1,230 gm of soil from Tract U-a. Soil dry bulk density was 1.48 gm/cm^3 and porosity was 35.7 percent.

[b] Pond water--from retention pond below processed-shale pile at Anvil Points experimental site.

[c] Process water--from shale oil-water separation; 1:1 mixture diluted to 7,000 µmhos/cm with deionized water.

[d] Simulated landfill leachate injected during experiment.

TABLE C-2. RESULTS OF ORGANIC FRACTIONATION ANALYSIS OF SAMPLES FROM SHAKER EXPERIMENTS

Experiment component			Organic fractionation (percent of DOC (mg/l DOC))					
			Hydrophobics			Hydrophilics		
Processed shale (grams)	Liquid	DOC (mg/l)	Bases	Acids	Neutral	Bases	Acids	Neutral
100	Deionized water	7.1	0 (0)	21 (1.5)	7 (0.5)	0 (0)	69 (4.9)	3 (0.2)
200	Deionized water	5.2	0 (0)	12 (0.6)	25 (1.3)	2 (0.1)	58 (3.0)	4 (0.2)
0	Process water	31.2	3 (1.0)	12 (3.7)	8 (2.6)	5 (1.5)	63 (19.6)	9 (2.8)
100	Process water	17.7	1 (0.2)	19 (3.3)	7 (1.2)	12 (2.2)	46 (8.2)	15 (2.6)
200	Process water	20.0	2 (0.4)	17 (3.3)	10 (1.9)	12 (2.4)	46 (9.1)	14 (2.9)
0	Product water	47.5	2 (0.9)	11 (5.1)	4 (2.1)	8 (4.0)	65 (30.8)	10 (4.6)
100	Product water	37.6	2 (0.6)	11 (4.2)	5 (1.8)	7 (2.8)	65 (24.4)	10 (3.8)
200	Product water	20.0	2 (0.3)	10 (1.9)	5 (0.9)	5 (1.0)	70 (14.0)	10 (1.9)
0	Pond water	7.6	3 (0.2)	1 (0.1)	26 (2.0)	10 (0.8)	33 (2.5)	26 (2.0)
100	Pond water	23.8	1 (0.2)	13 (3.0)	10 (2.3)	3 (0.8)	37 (8.9)	36 (8.6)
200	Pond water	13.7	1 (0.1)	10 (1.4)	12 (1.6)	5 (0.7)	34 (4.7)	38 (5.2)

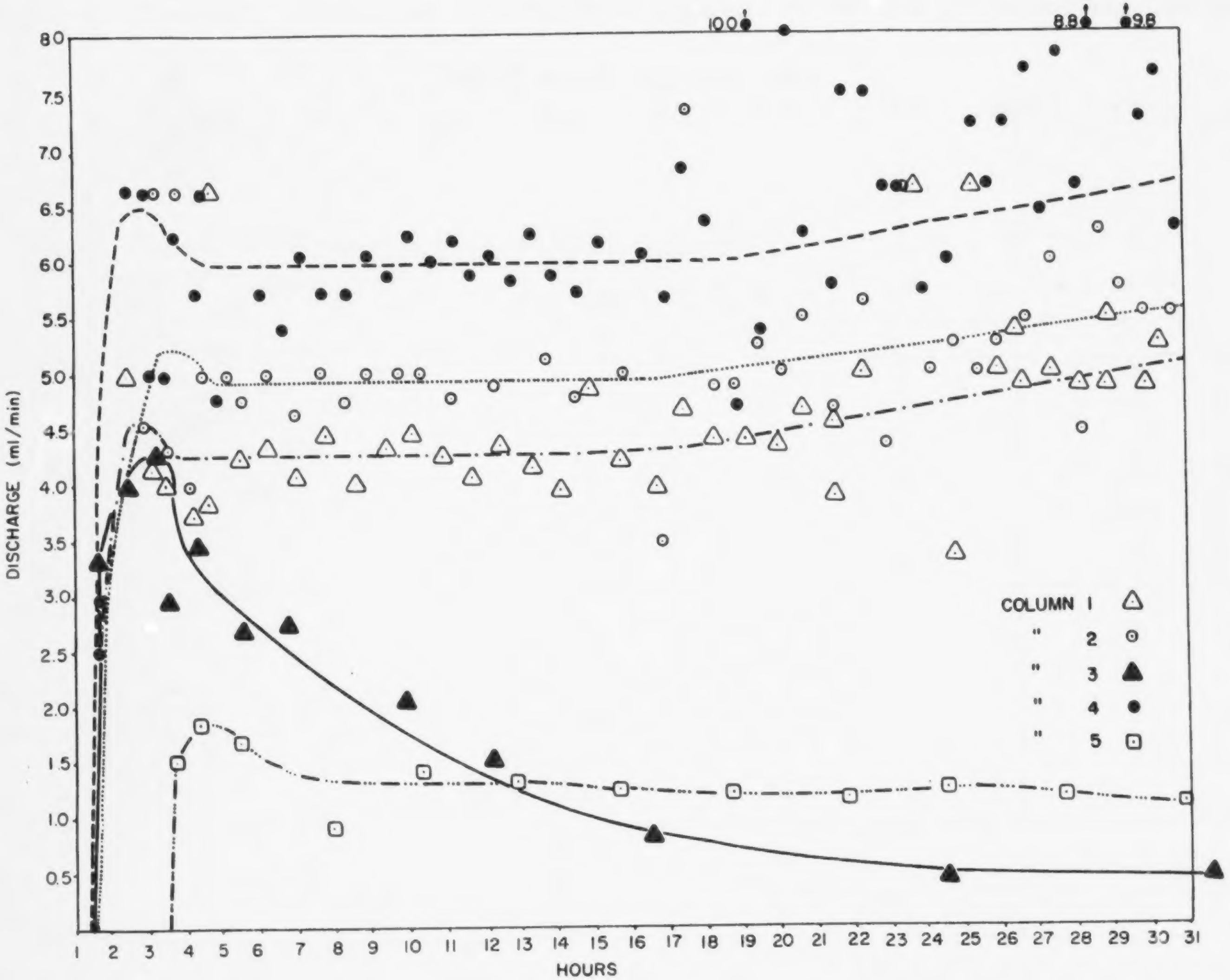

Figure C-1. Discharge vs. time plot for column experiments.

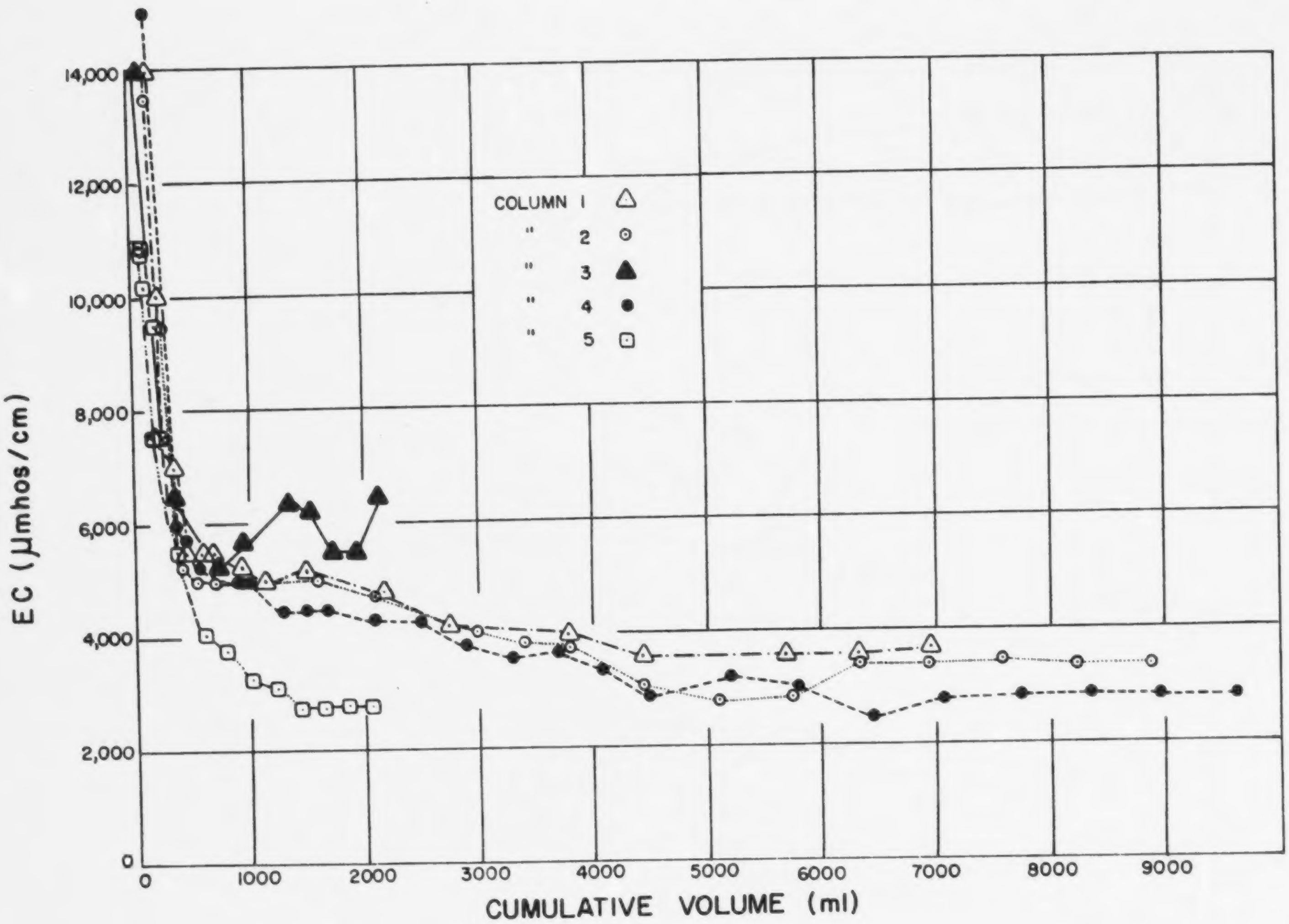

Figure C-2. Electrical conductivity vs. cumulative discharge volume plot for column experiments.

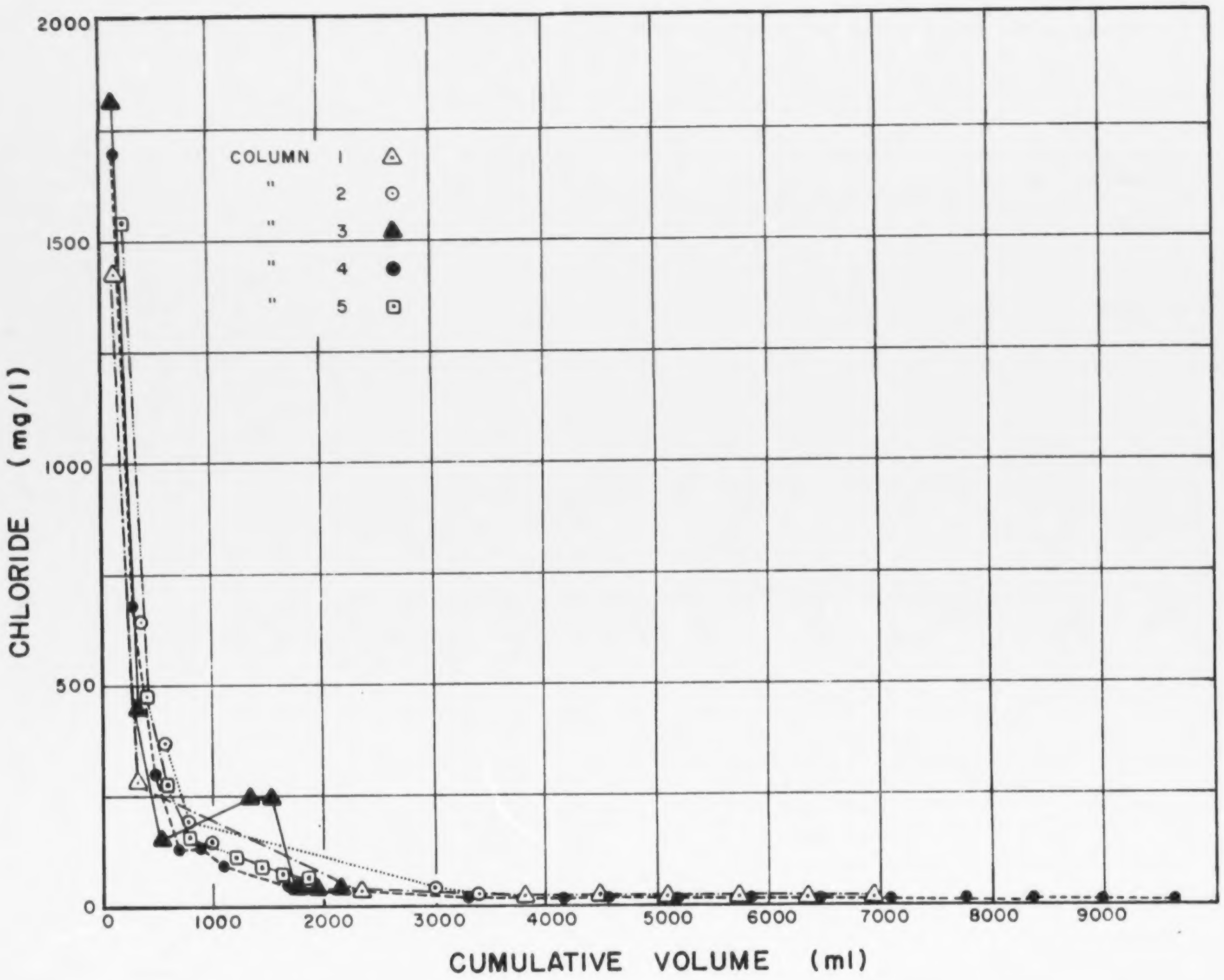

Figure C-3. Chloride vs. cumulative discharge volume plot for column experiments.

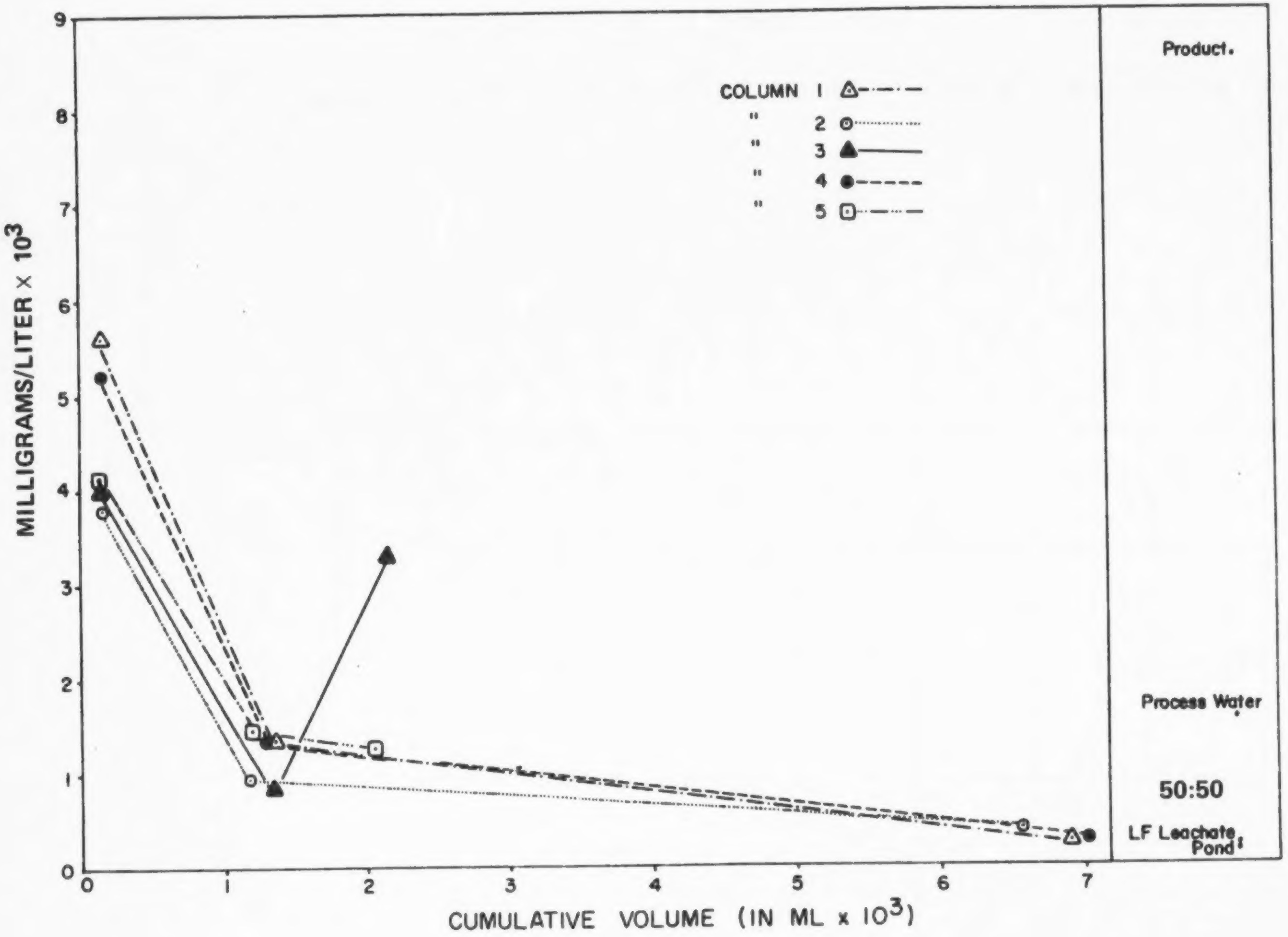

Figure C-4. Sulfate vs. cumulative discharge volume plot for column experiments.

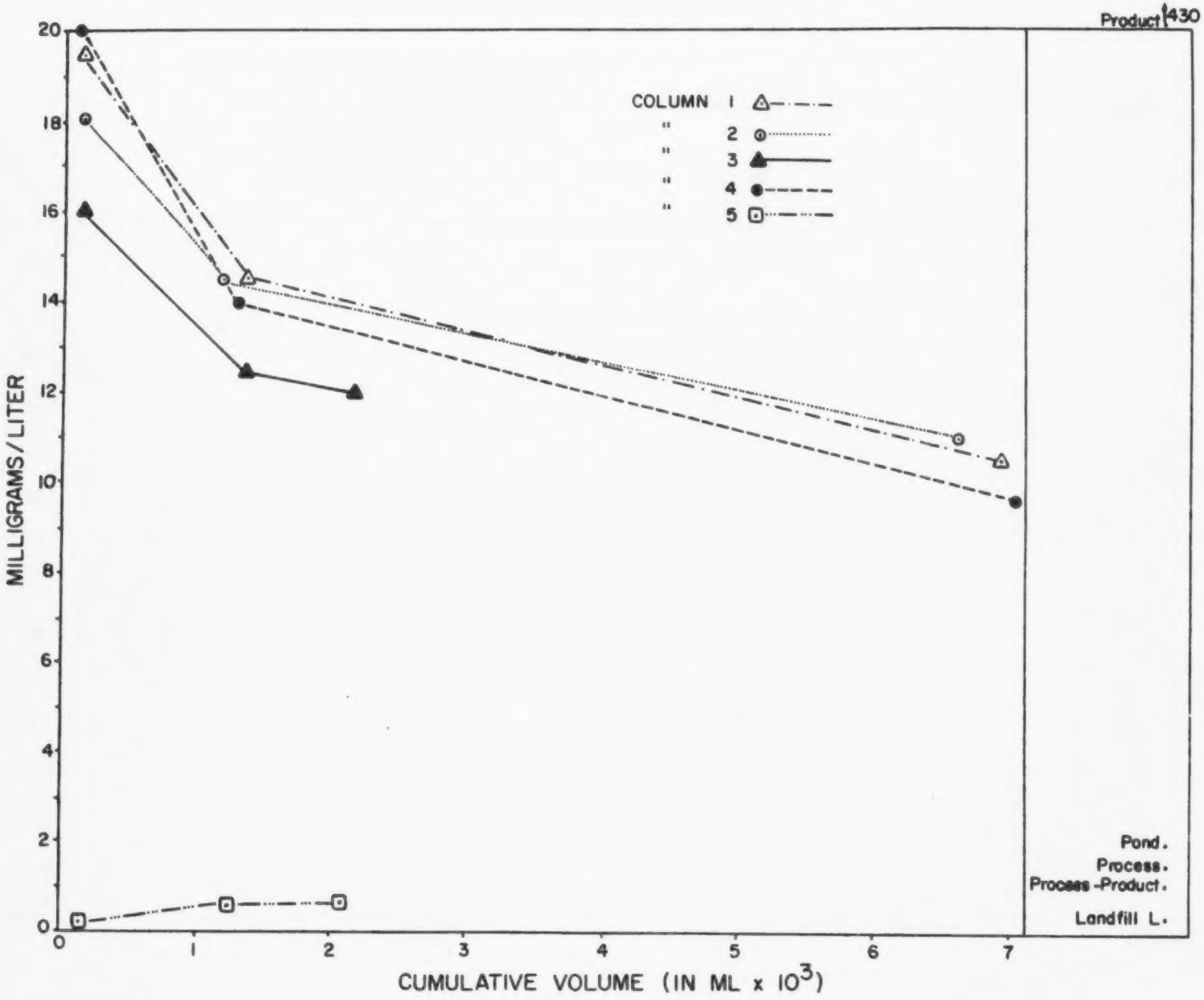

Figure C-5. Fluoride vs. cumulative discharge volume plot for column experiments.

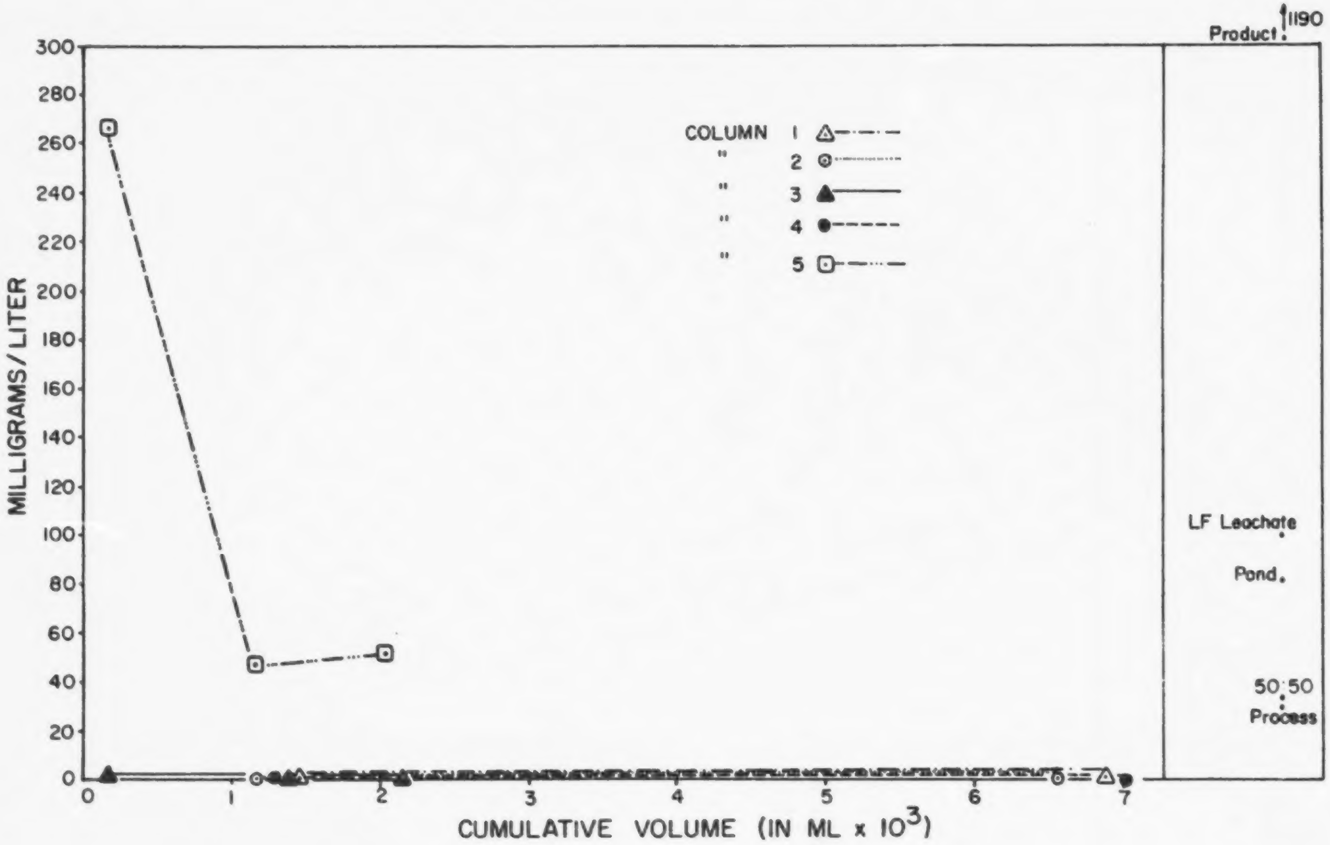

Figure C-6. Magnesium vs. cumulative discharge volume plot for column experiments.

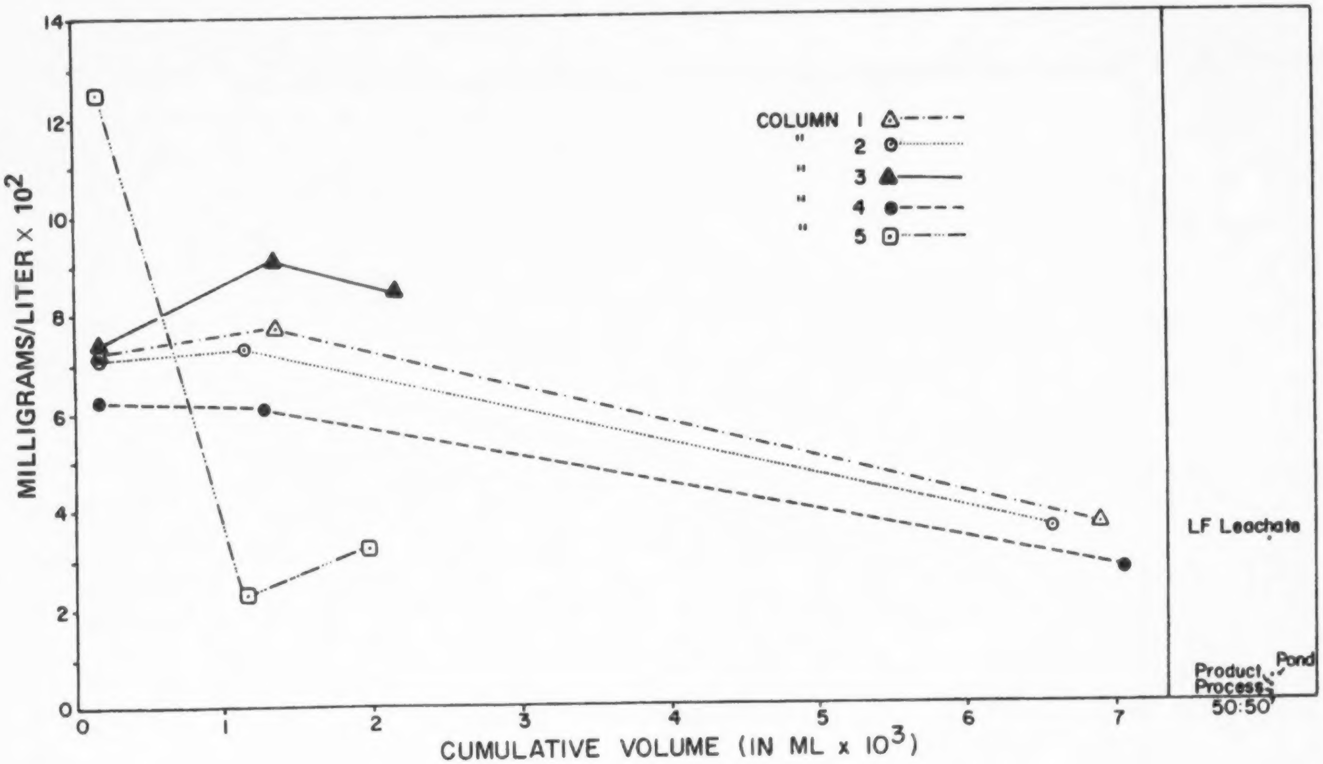

Figure C-7. Calcium vs. cumulative discharge volume plot for column experiments.

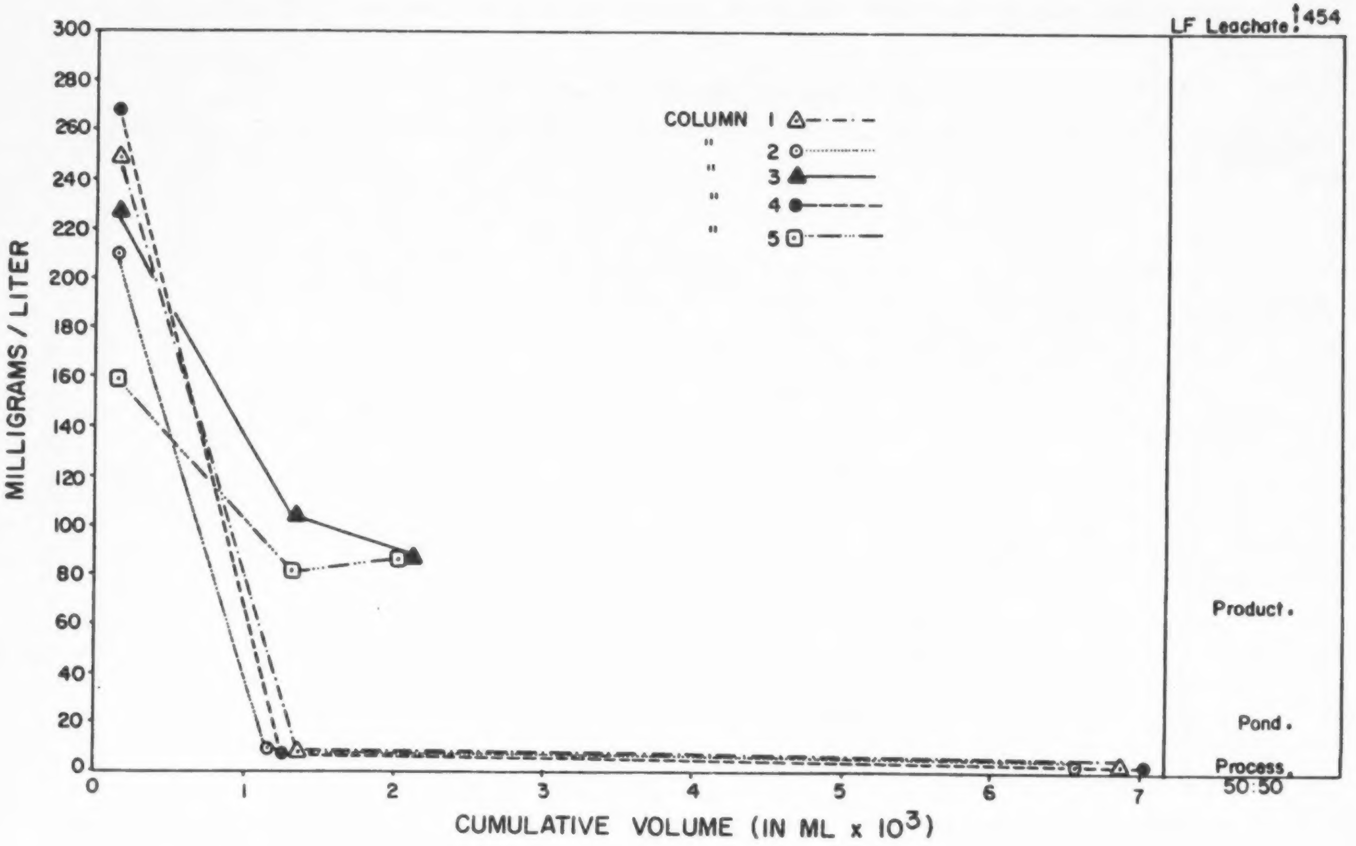

Figure C-8. Potassium vs. cumulative discharge volume plot for column experiments.

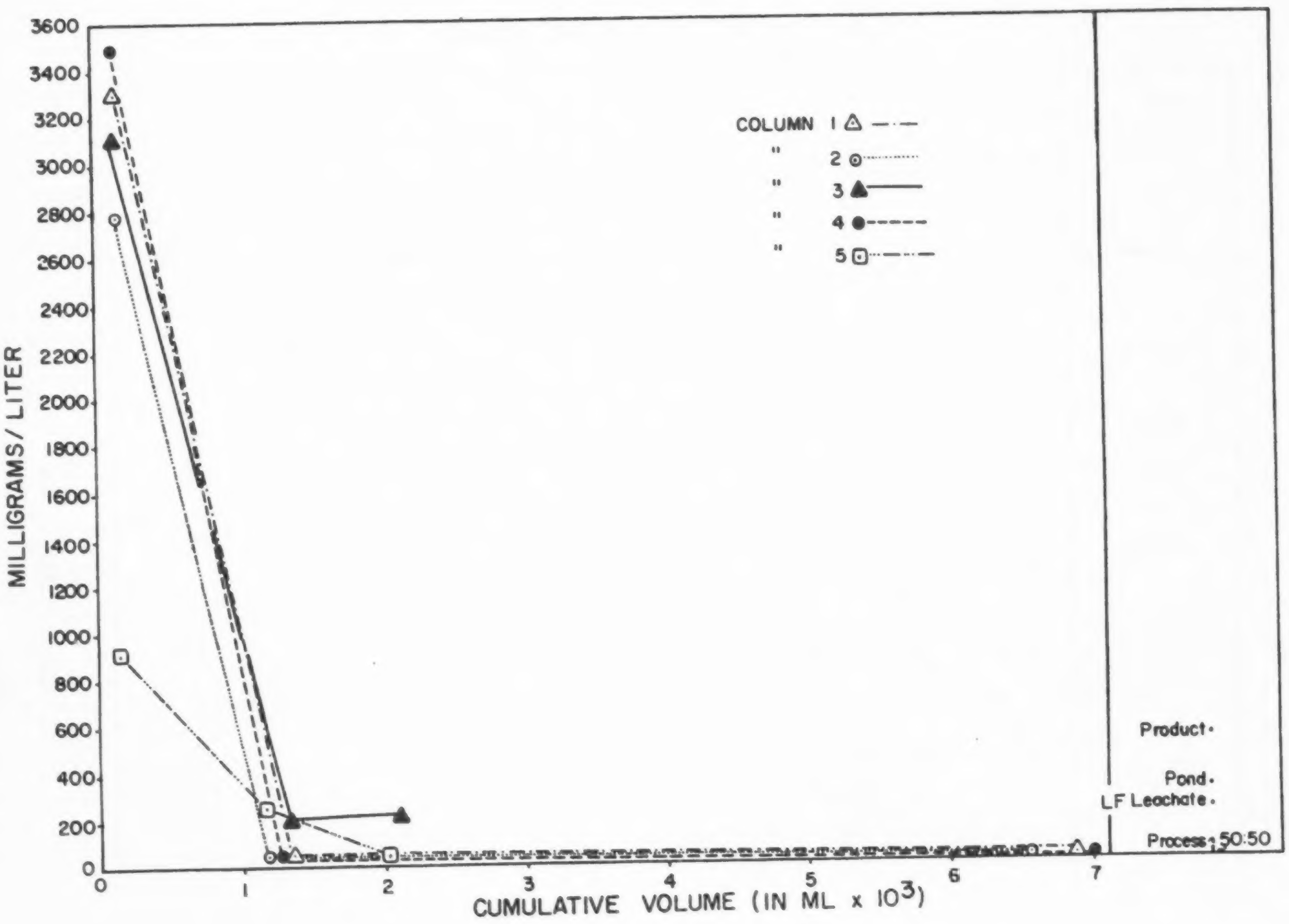

Figure C-9. Sodium vs. cumulative discharge volume plot for column experiments.

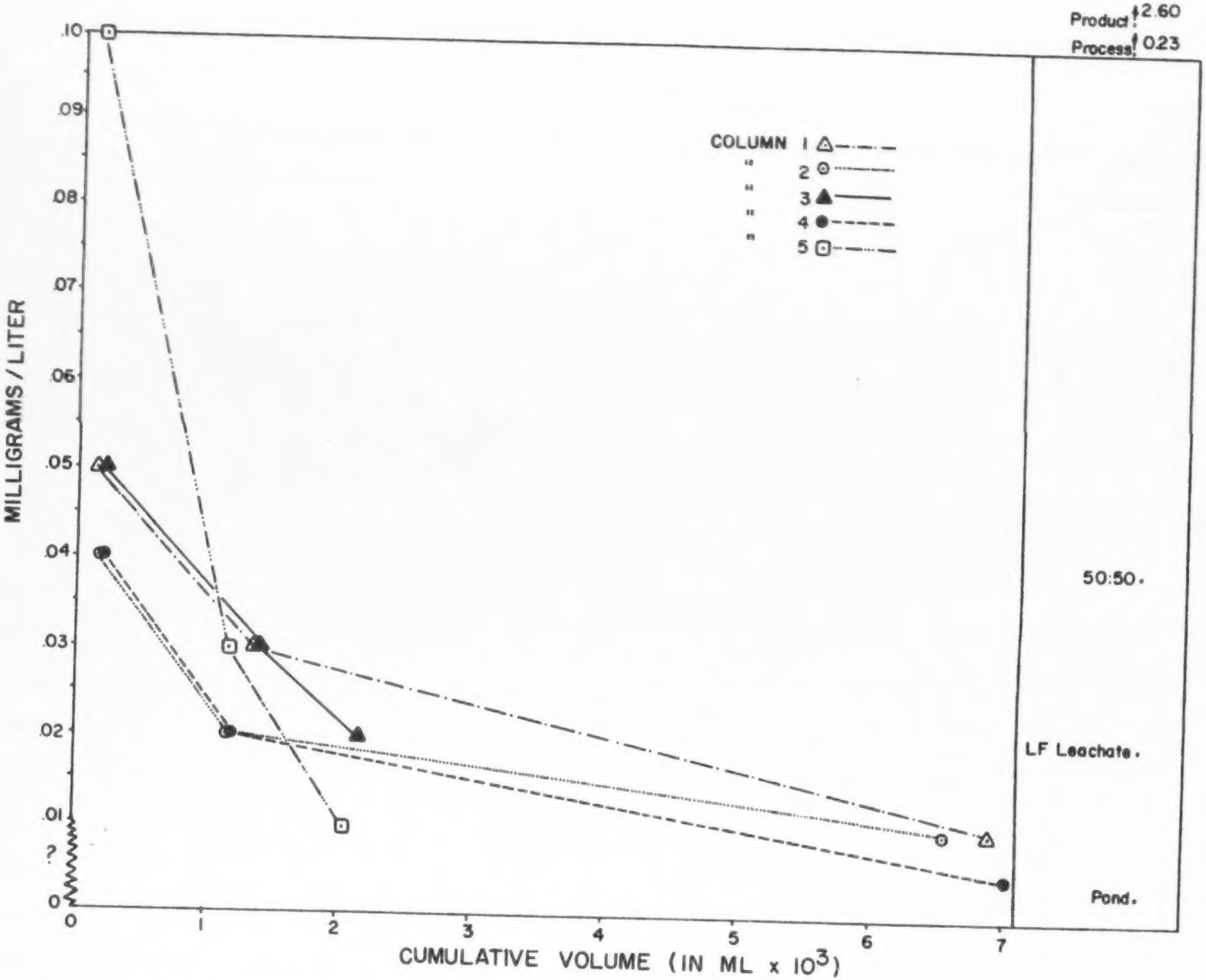

Figure C-10. Copper vs. cumulative discharge volume plot for column experiments.

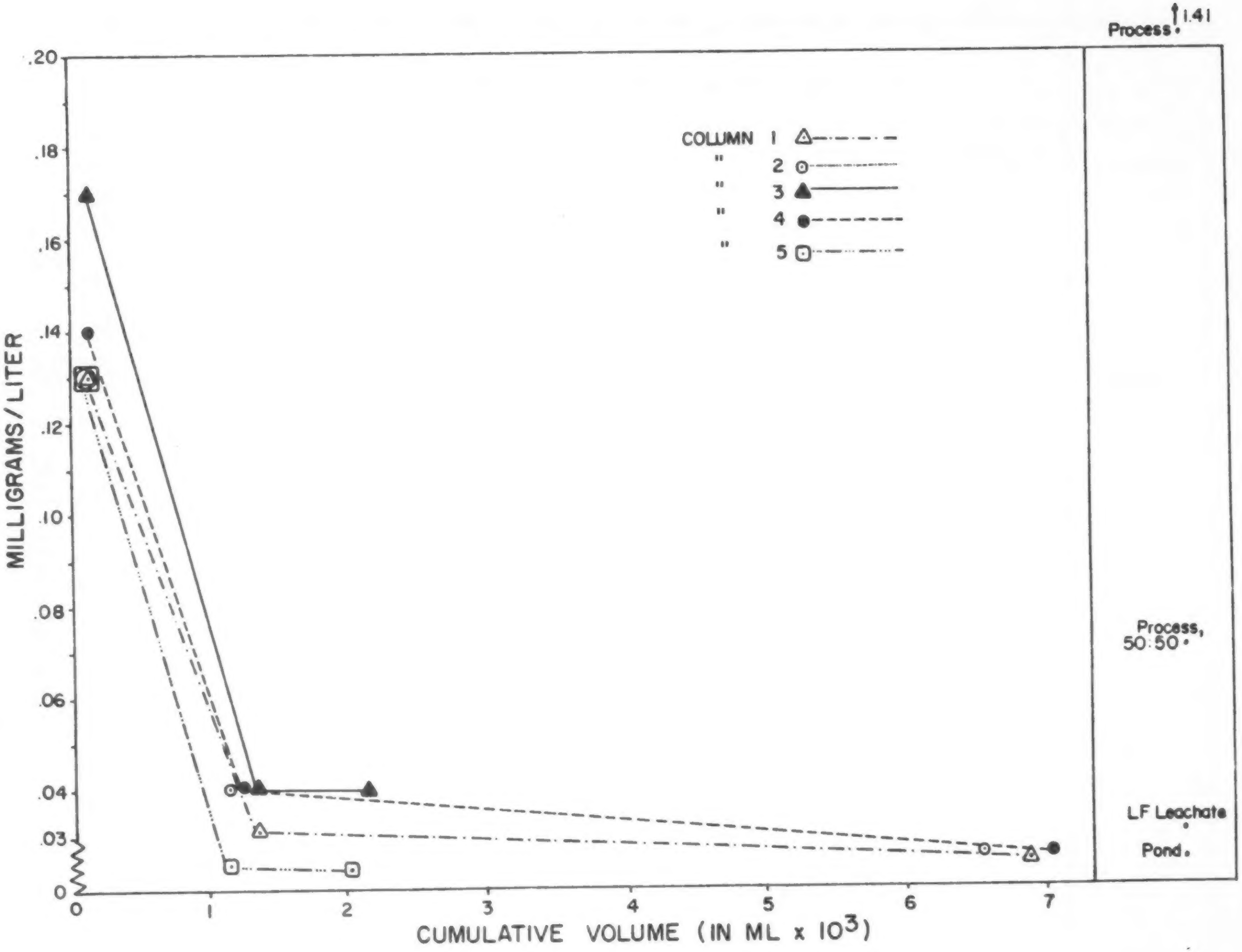

Figure C-11. Nickel vs. cumulative discharge volume plot for column experiments.

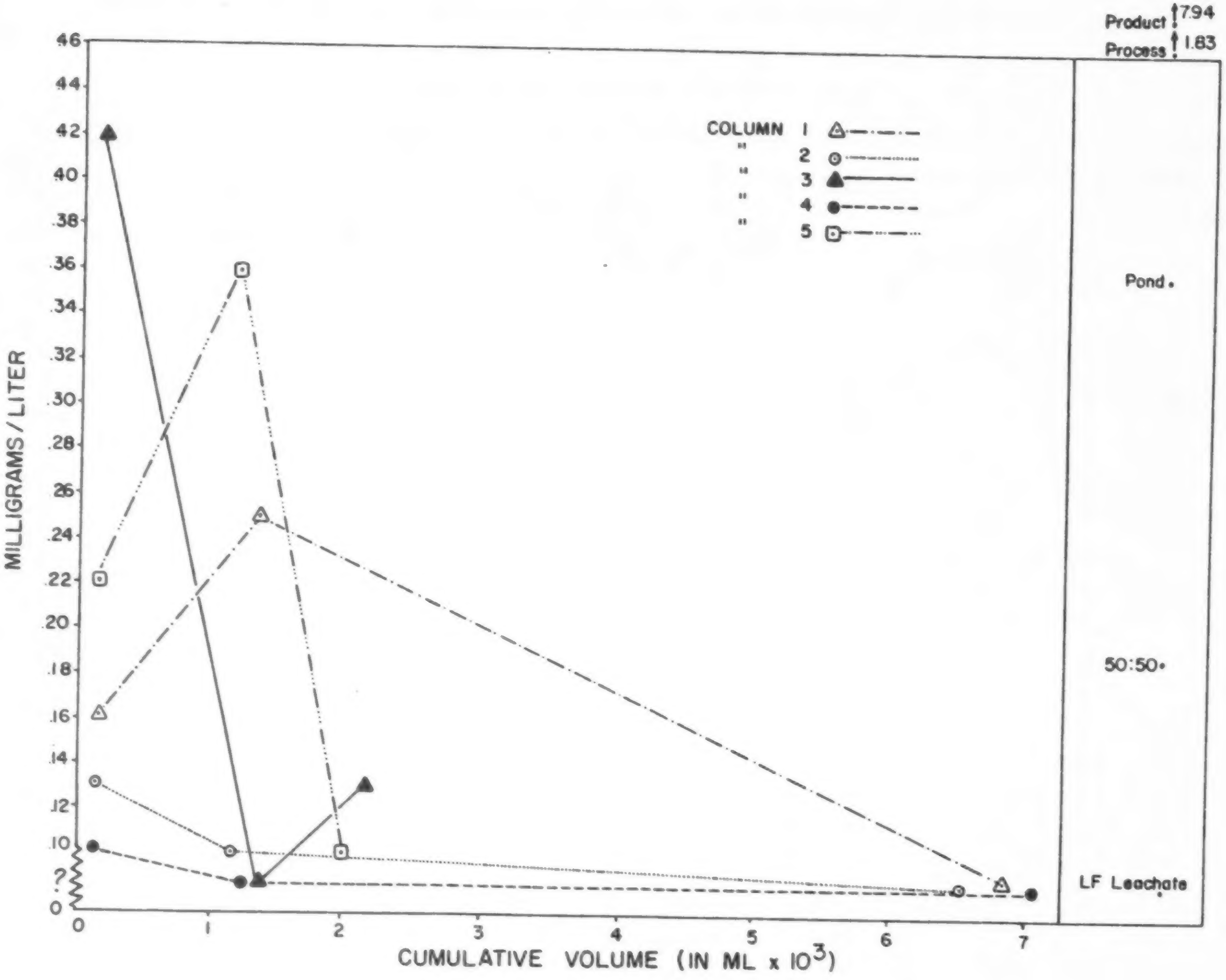

Figure C-12. Selenium vs. cumulative discharge volume plot for column experiments.

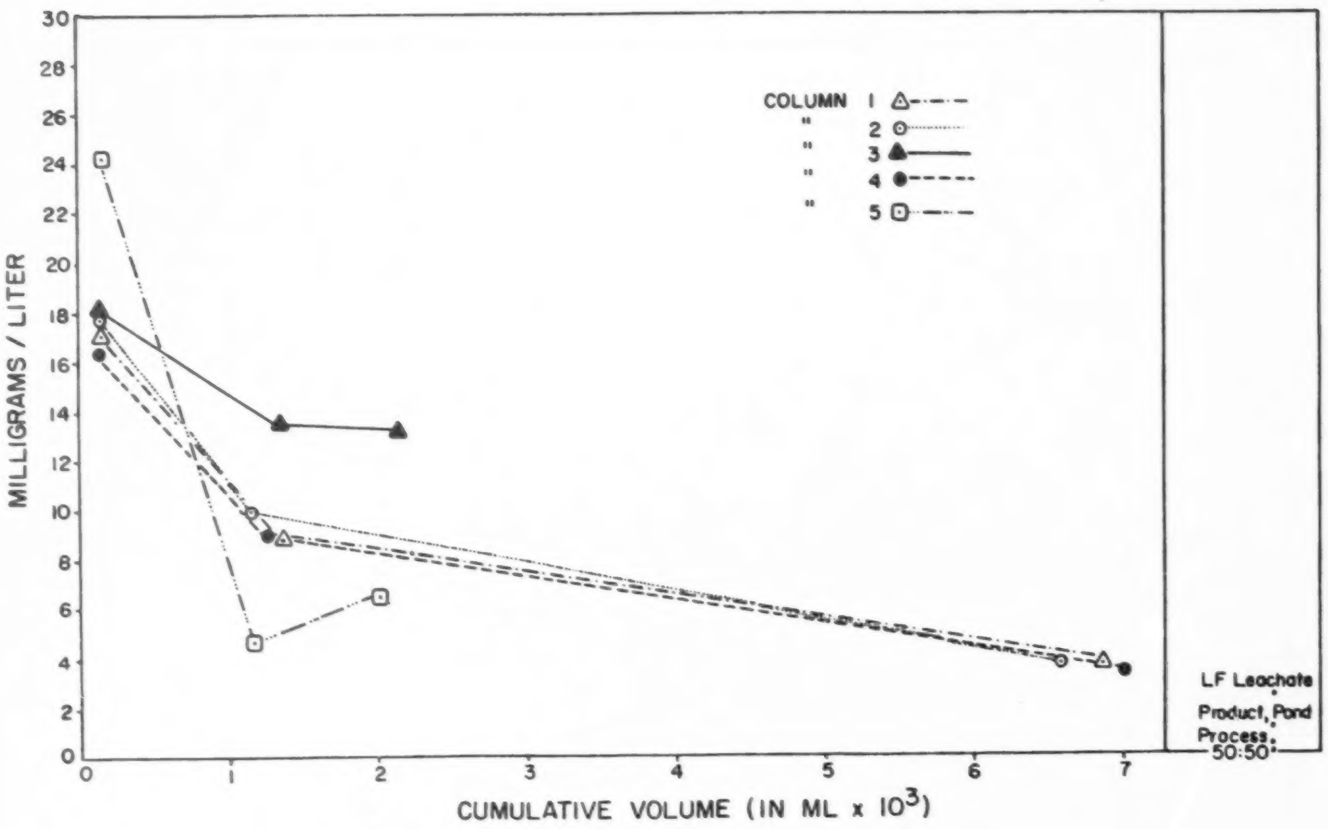

Figure C-13. Strontium vs. cumulative discharge volume plot for column experiments.

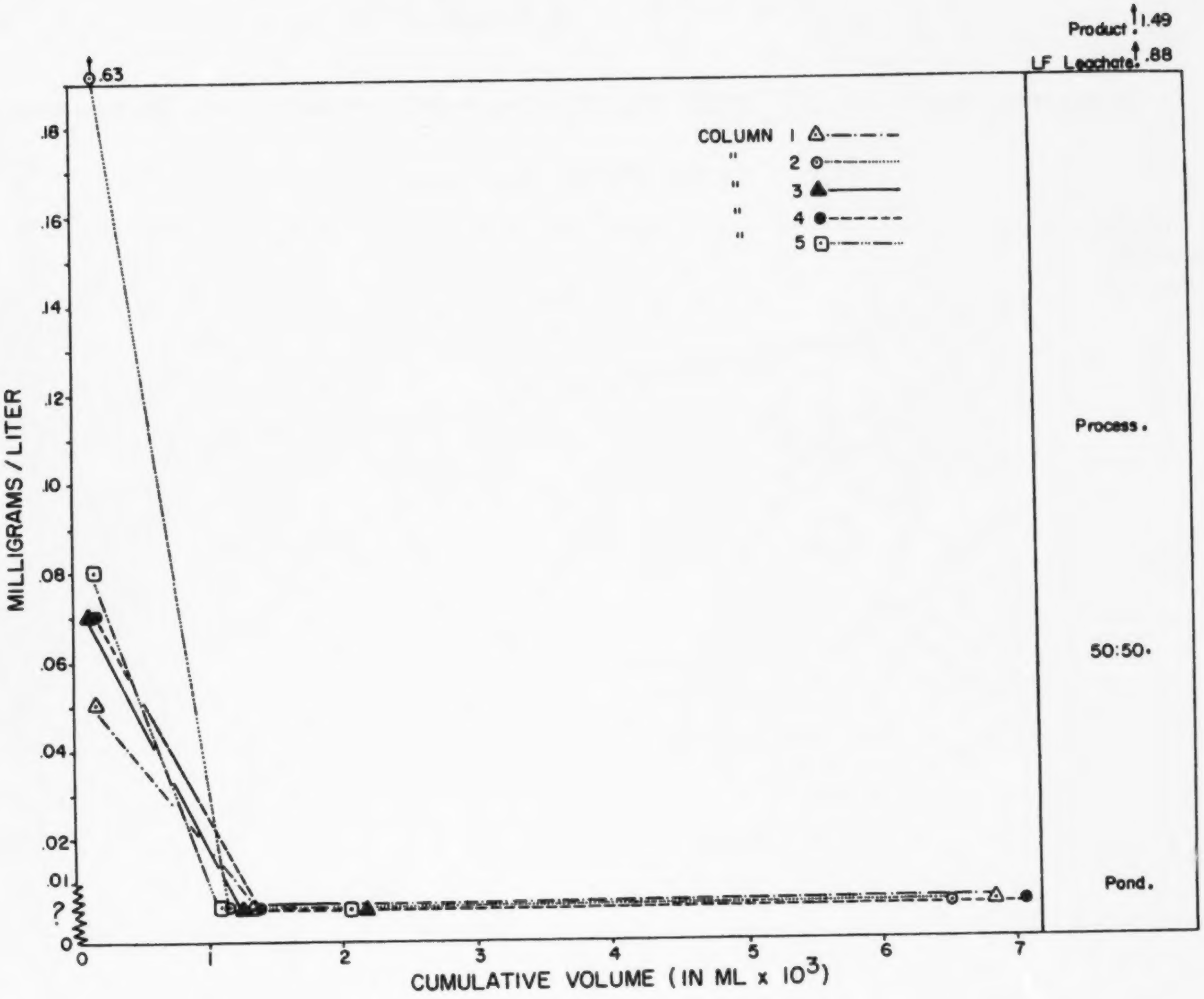

Figure C-14. Zinc vs. cumulative discharge volume plot for column experiments.

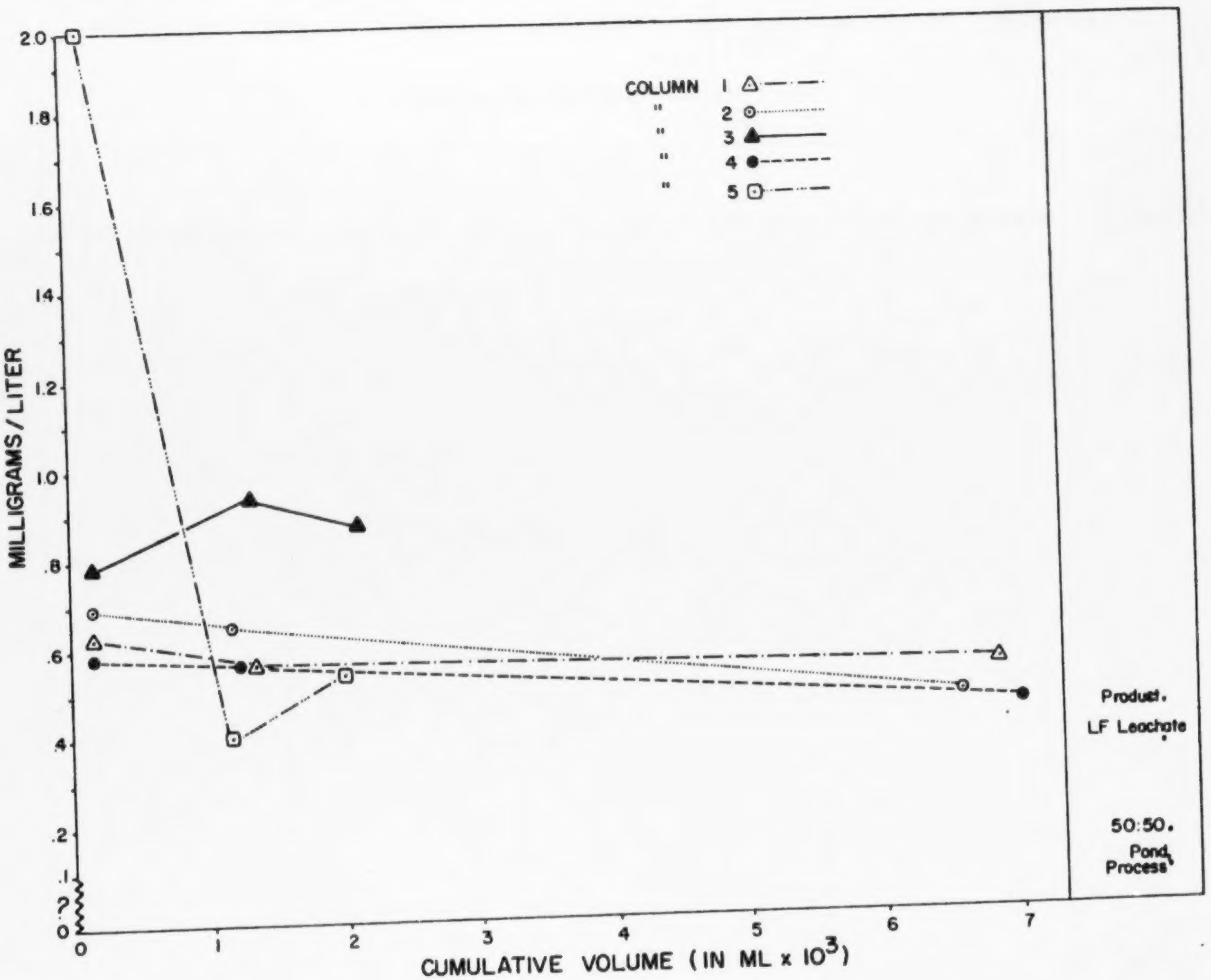

Figure C-15. Barium vs. cumulative discharge volume plot for column experiments.

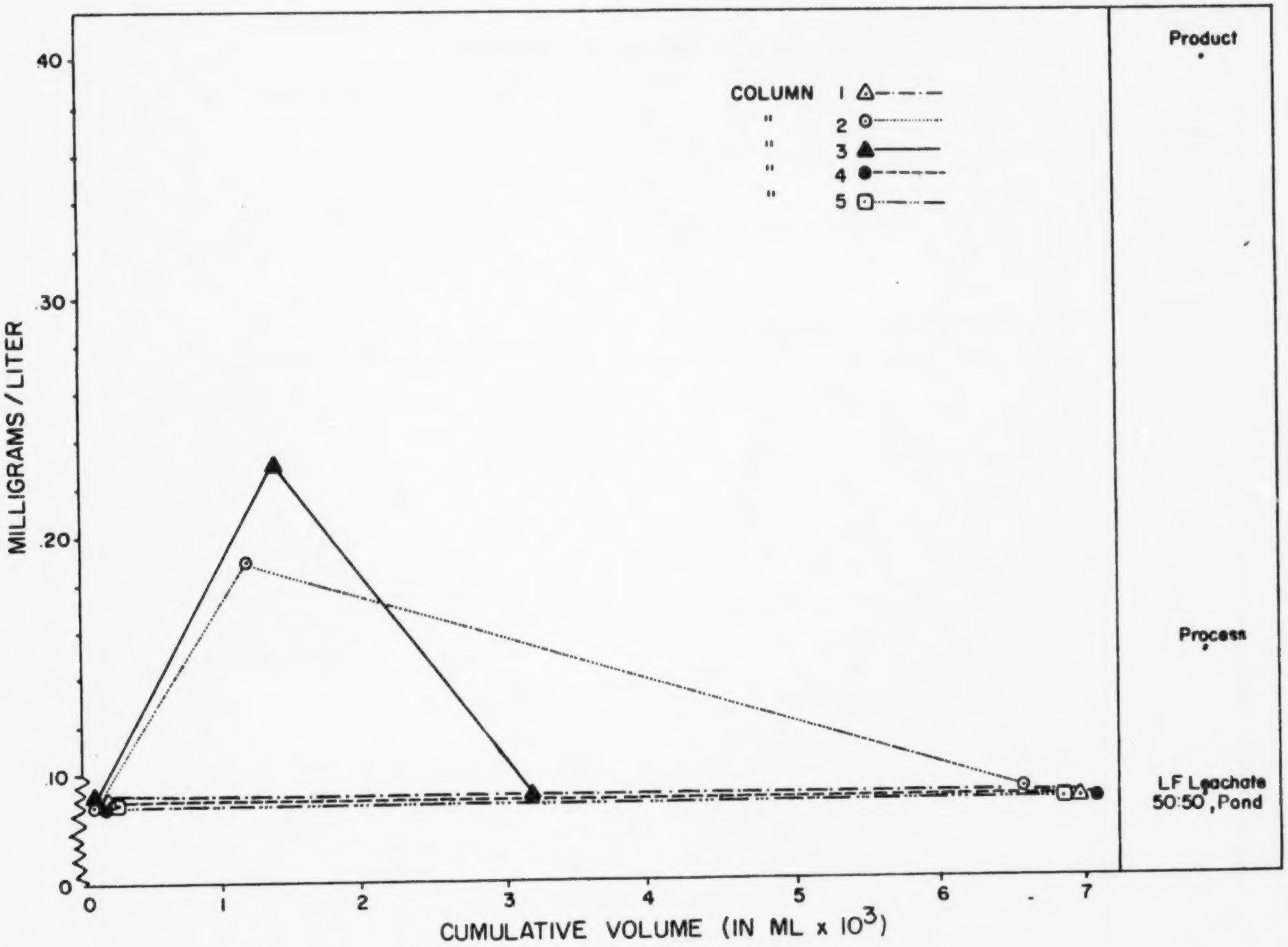

Figure C-16. Lead vs. cumulative discharge volume plot for column experiments.

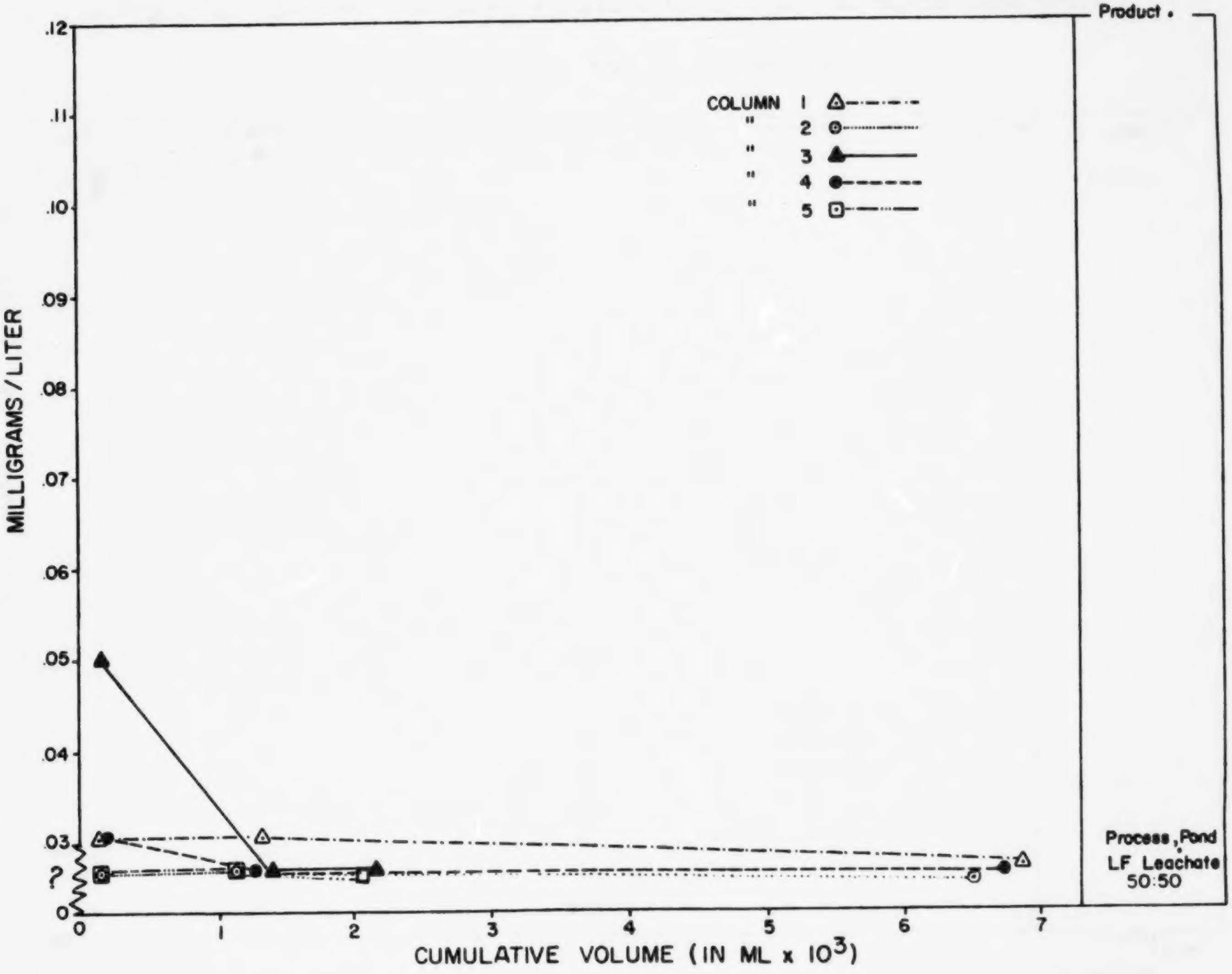

Figure C-17. Chromium vs. cumulative discharge volume plot for column experiments.

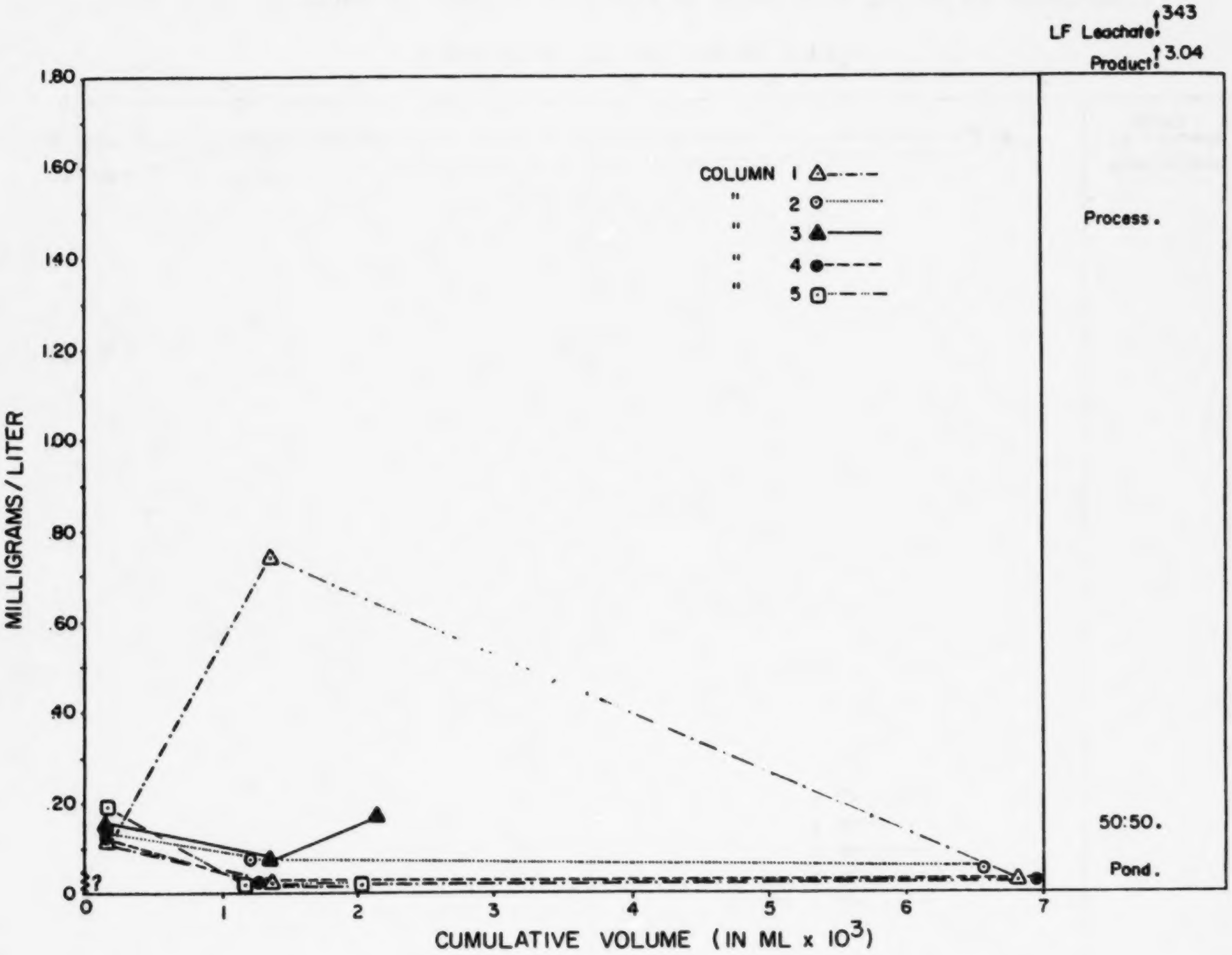

Figure C-18. Iron vs. cumulative discharge volume plot for column experiments.

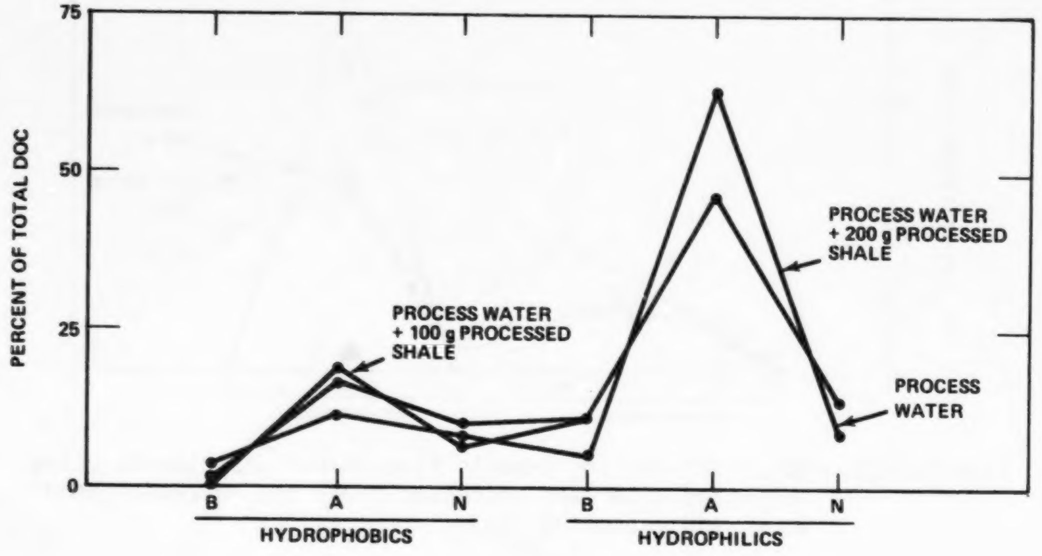

Figure C-19. DOC fractionation results from shaker experiments using process water and processed shale.

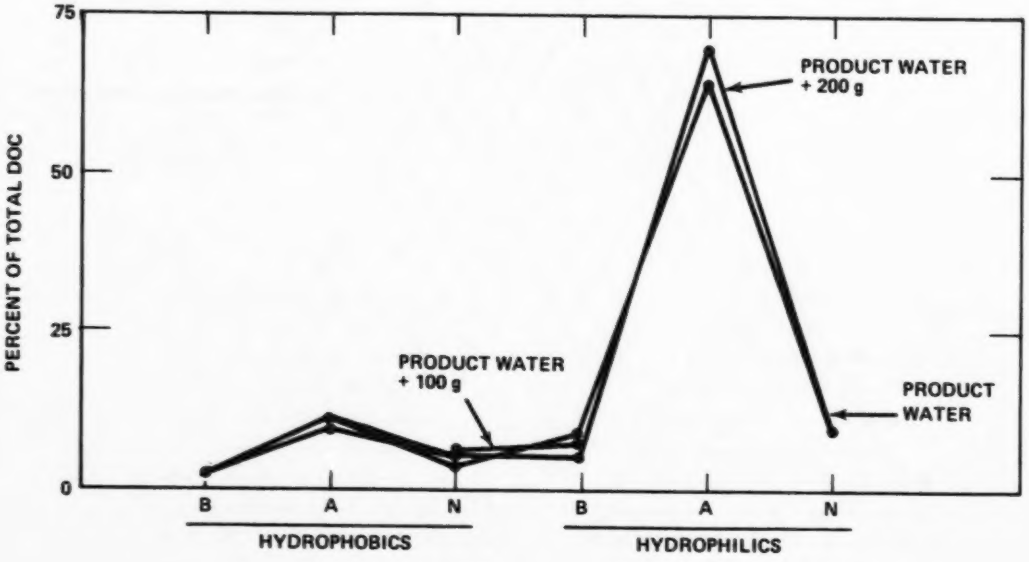

Figure C-20. DOC fractionation results from shaker experiments using product water and processed shale.

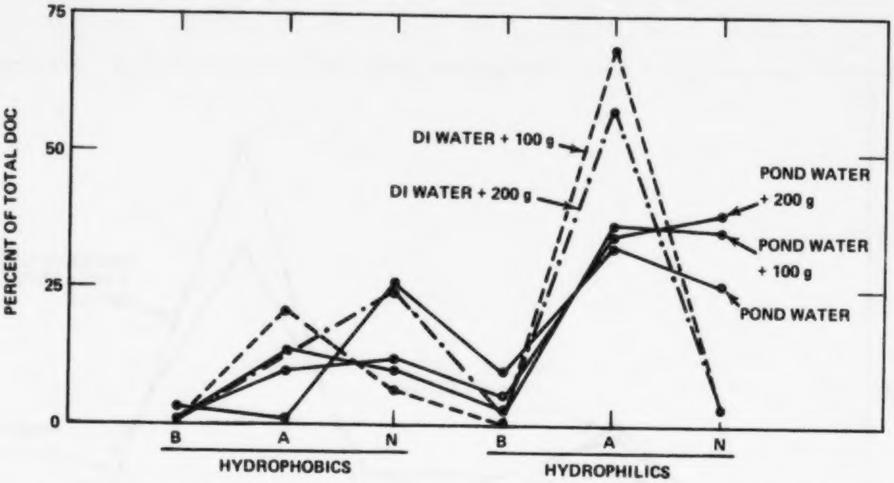

Figure C-21. DOC fractionation results from shaker experiments using deionized water and processed shale and retention pond water and processed shale.

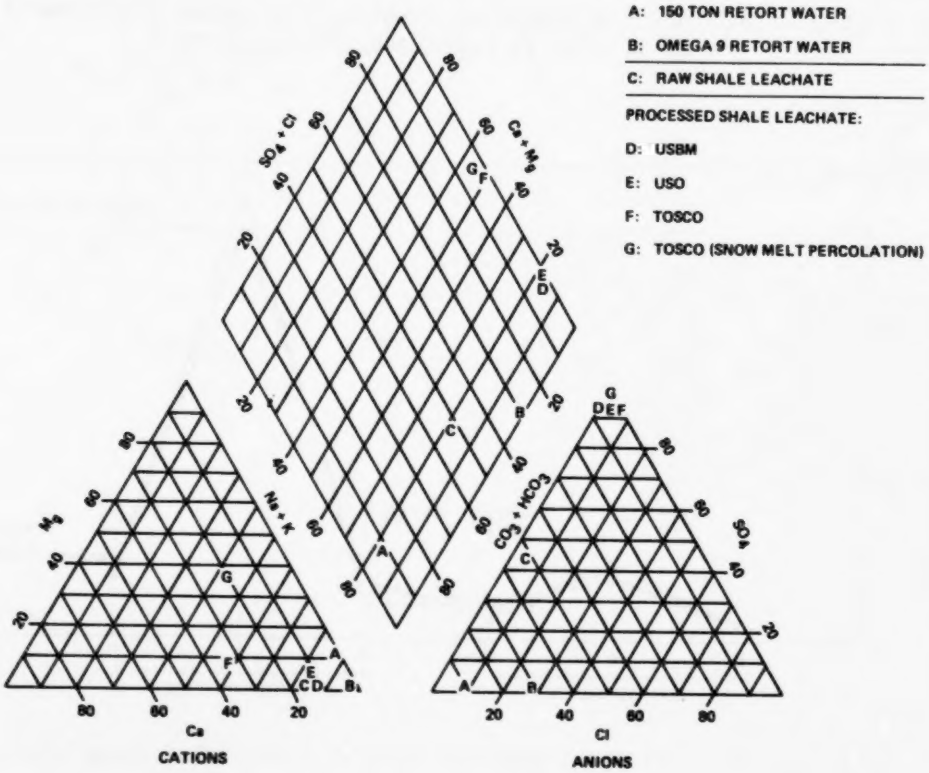

Figure C-22. Inorganic analyses of leachate from processed shale columns (data are from Ward, 1971, 1972; Stuber and Leenheer, 1978).

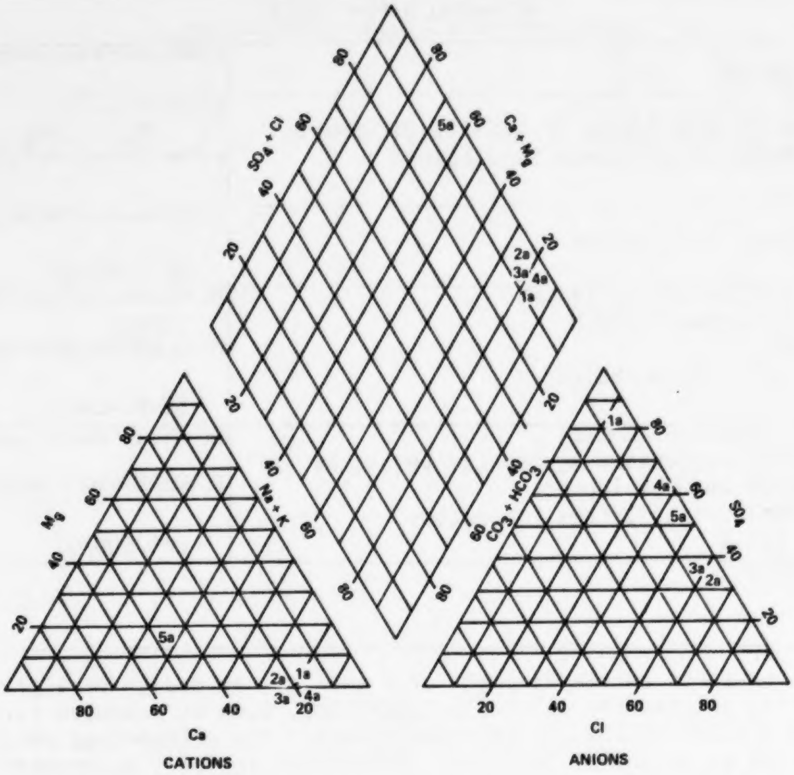

Figure C-23. Trilinear diagram showing plot of chemical analysis of initial leachate samples (1a, 2a, 3a, 4a, 5a) from column experiments (column descriptions are provided in Table C-1).

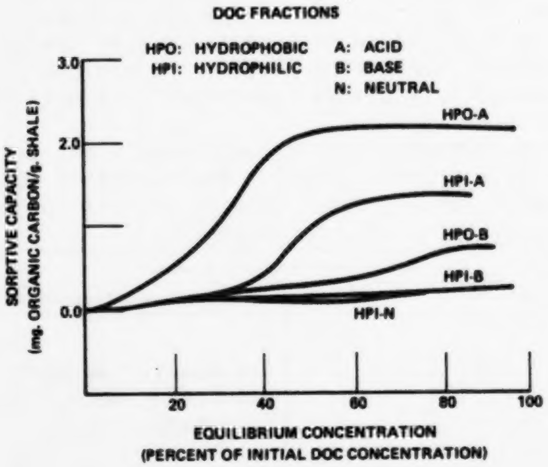

Figure C-24. Sorption of 150-ton retort water organic fractions on TOSCO II processed shale (from Stuber and Leenheer, 1978).

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